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Comb et al.

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(45) **Date of Patent: Jan. 6, 2015**

(54) **HEAD TOOL CHANGER FOR USE WITH DEPOSITION-BASED DIGITAL MANUFACTURING SYSTEMS**

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(73) Assignee: **Stratasys, Inc.**, Eden Prairie, MN (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 945 days.

(21) Appl. No.: **13/074,523**

(22) Filed: **Mar. 29, 2011**

Related U.S. Application Data

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(51) **Int. Cl.**
B29C 67/00 (2006.01)
B23Q 3/155 (2006.01)

(52) **U.S. Cl.**
CPC ***B23Q 3/155*** (2013.01); ***B29C 67/0051*** (2013.01); ***B23Q 3/15506*** (2013.01); ***B23Q 3/15566*** (2013.01); *Y10S 483/901* (2013.01)
USPC **483/16**; 700/119; 483/901; 483/4; 483/10; 425/162; 425/186; 425/190; 425/225; 425/375

(58) **Field of Classification Search**
CPC .. B23Q 3/155; B23Q 3/15506; B23Q 3/1556; B23Q 3/15566
USPC .... 700/118, 119, 120; 425/162, 166, 186, 425/190, 192 R, 225, 227, 375; 483/4, 7, 10, 483/11, 16, 901
See application file for complete search history.

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Primary Examiner — Erica E Cadugan
Assistant Examiner — Michael Vitale
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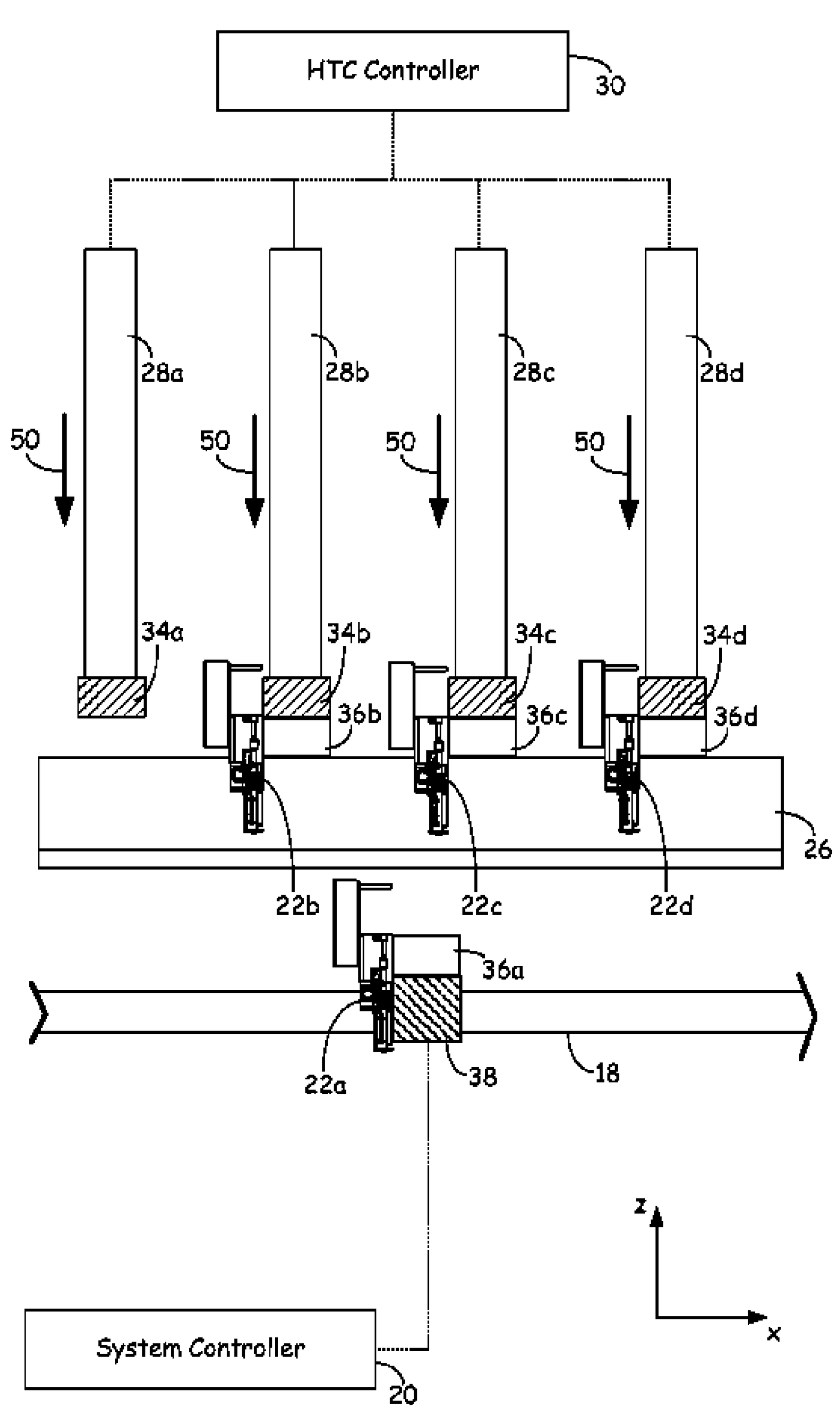
(57) **ABSTRACT**

A head tool changer for use with a deposition-based digital manufacturing system, the head tool changer comprising a tooling unit configured to retain a deposition head, a grip unit configured to engage with tooling unit and to relay electrical power to the tooling unit, and a master unit operably mounted to a gantry and configured to engage with the tooling unit and to relay electrical power to the tooling unit.

14 Claims, 30 Drawing Sheets



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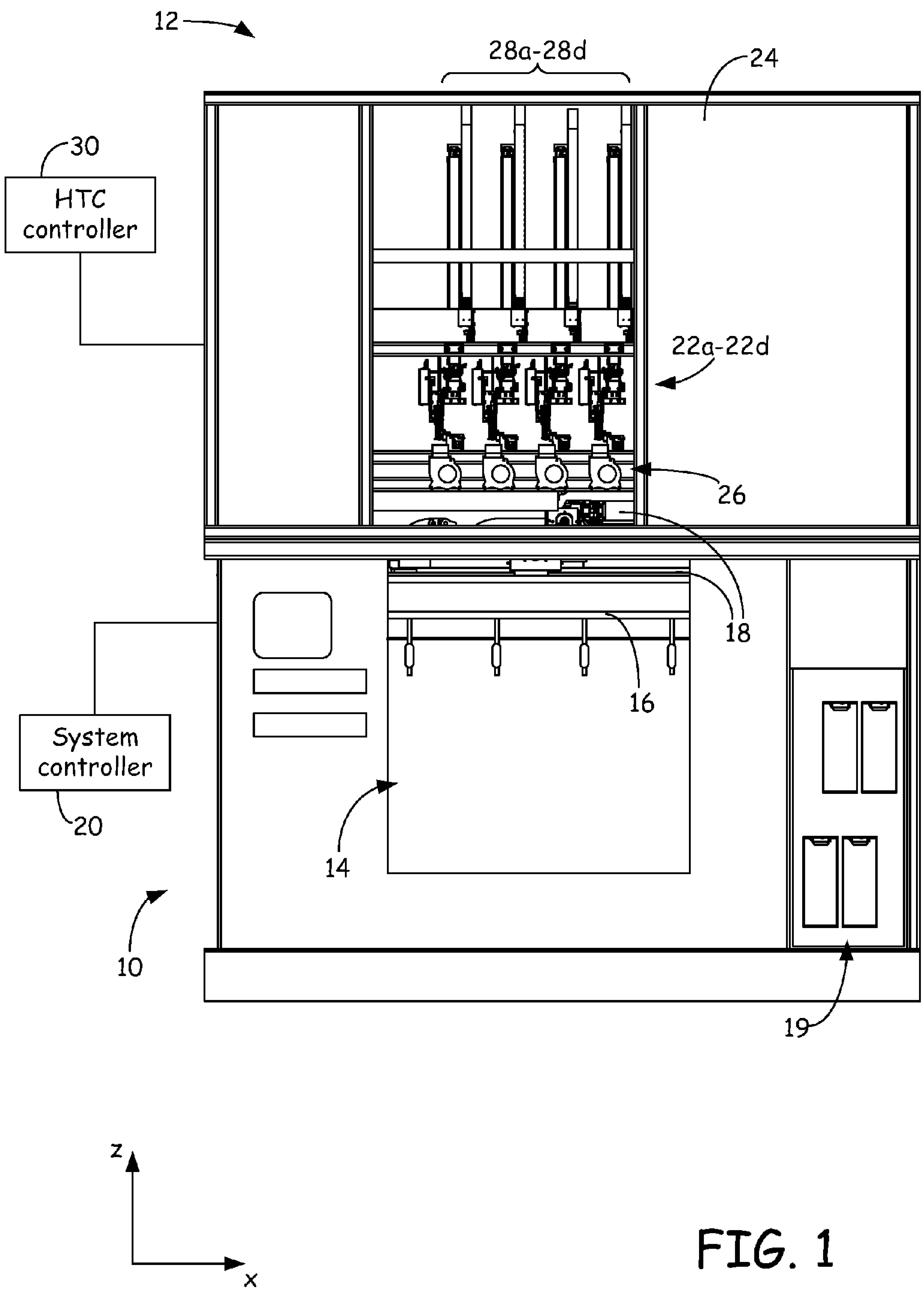

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HTC controller
22a-22d
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18
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System controller
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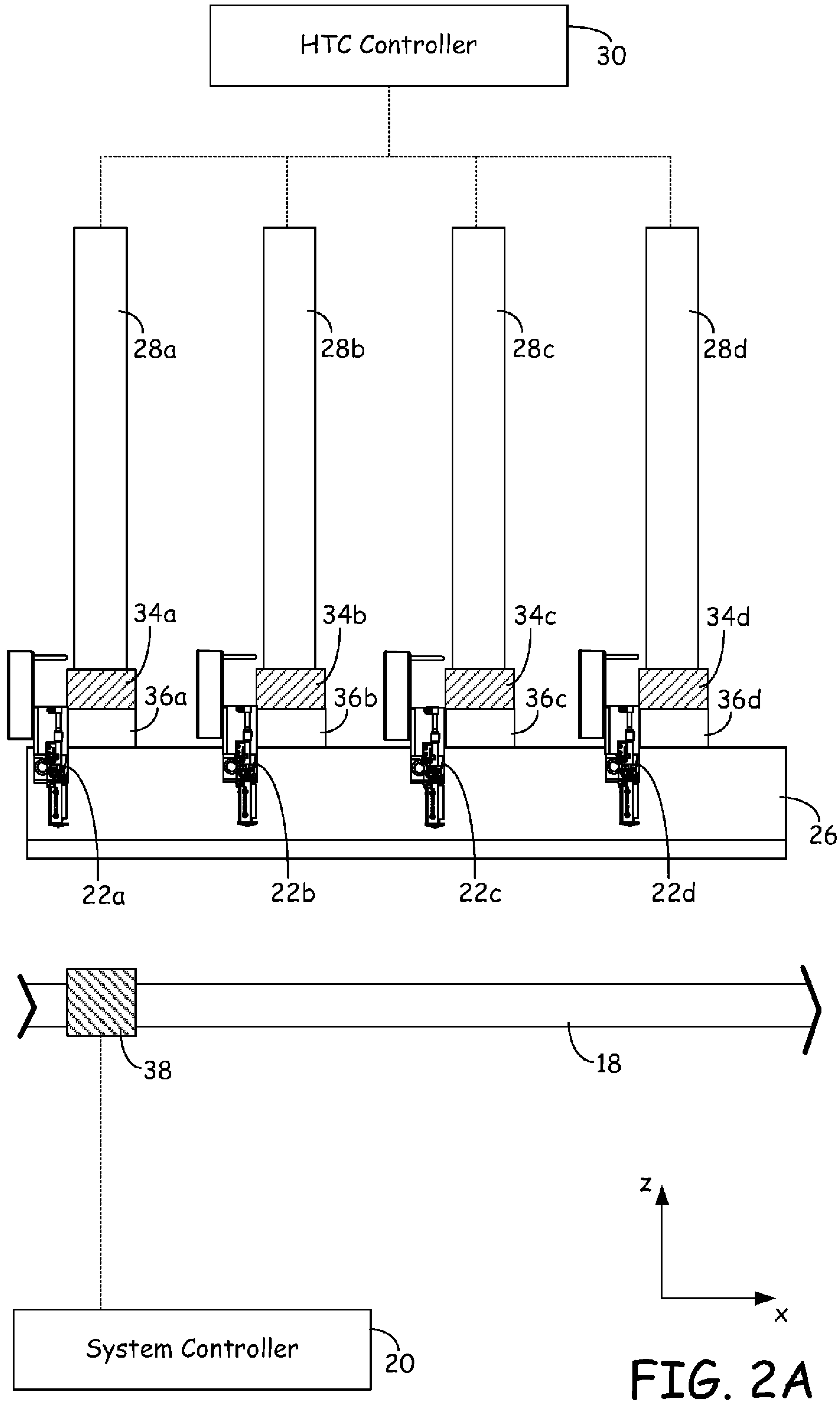
14
10
19
z
x

FIG. 1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22d
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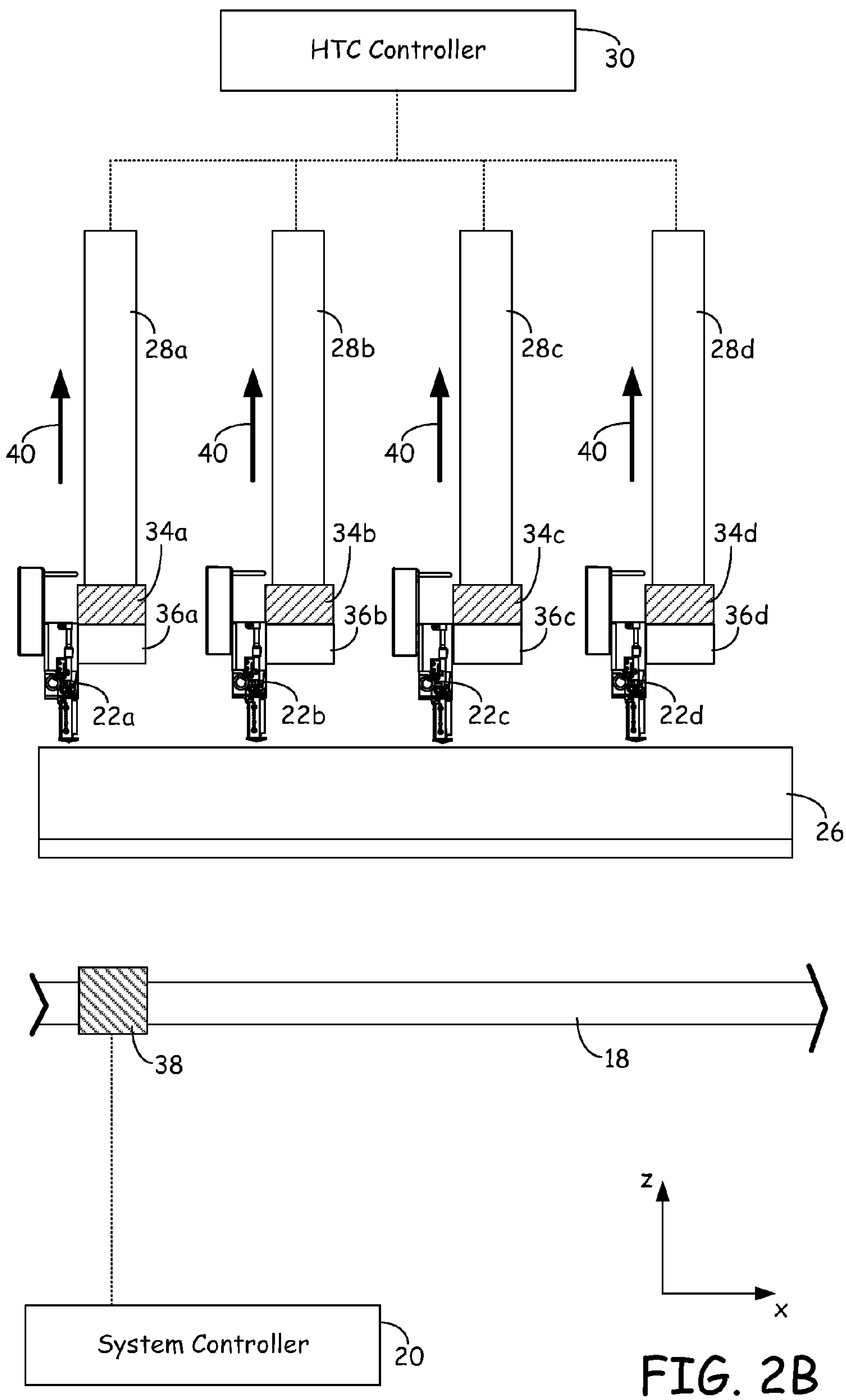
18
z
x
System Controller
20

FIG. 2A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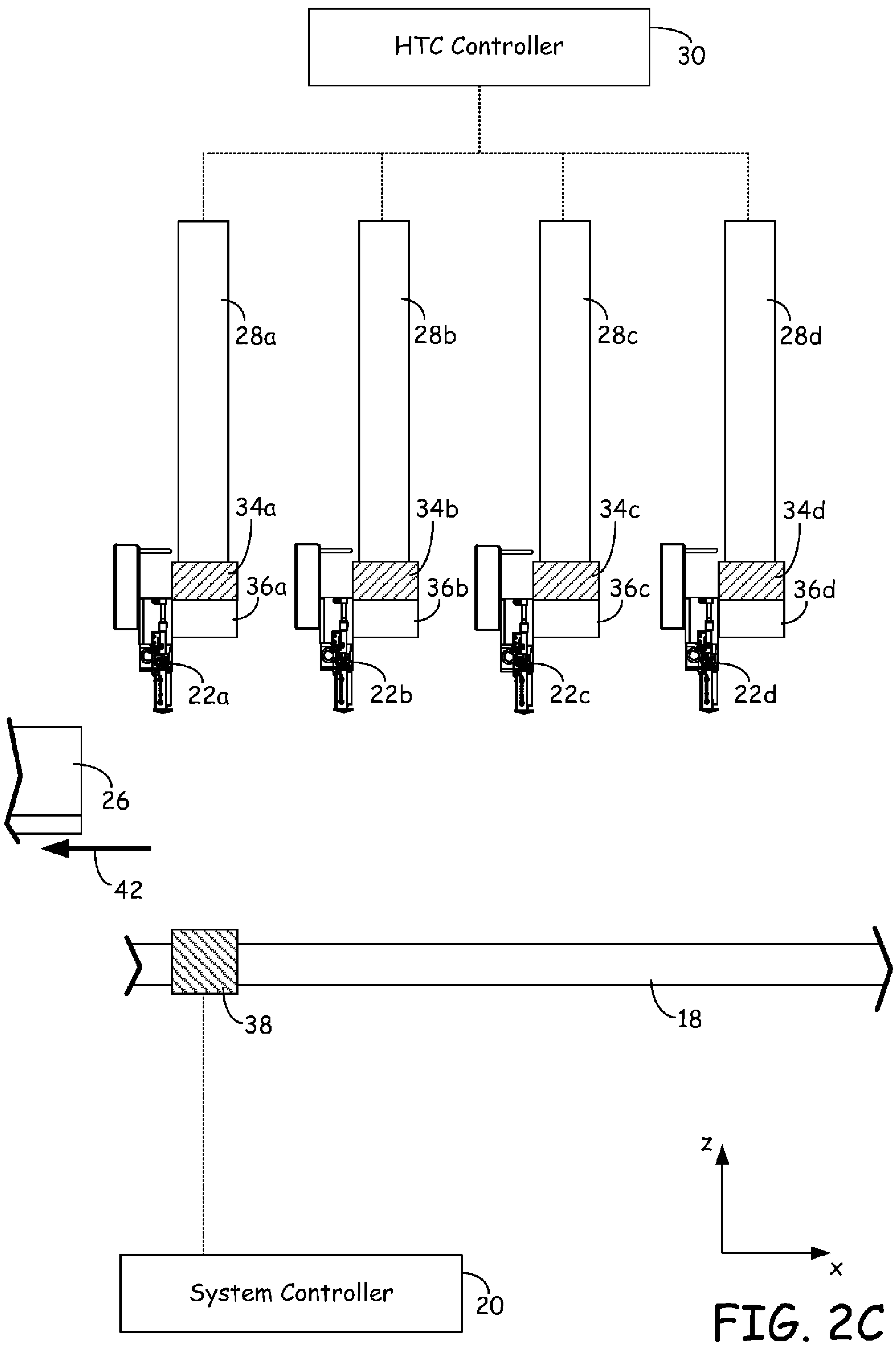
22c
22d
26
38
18
z
x
System Controller
20

FIG. 2B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22d
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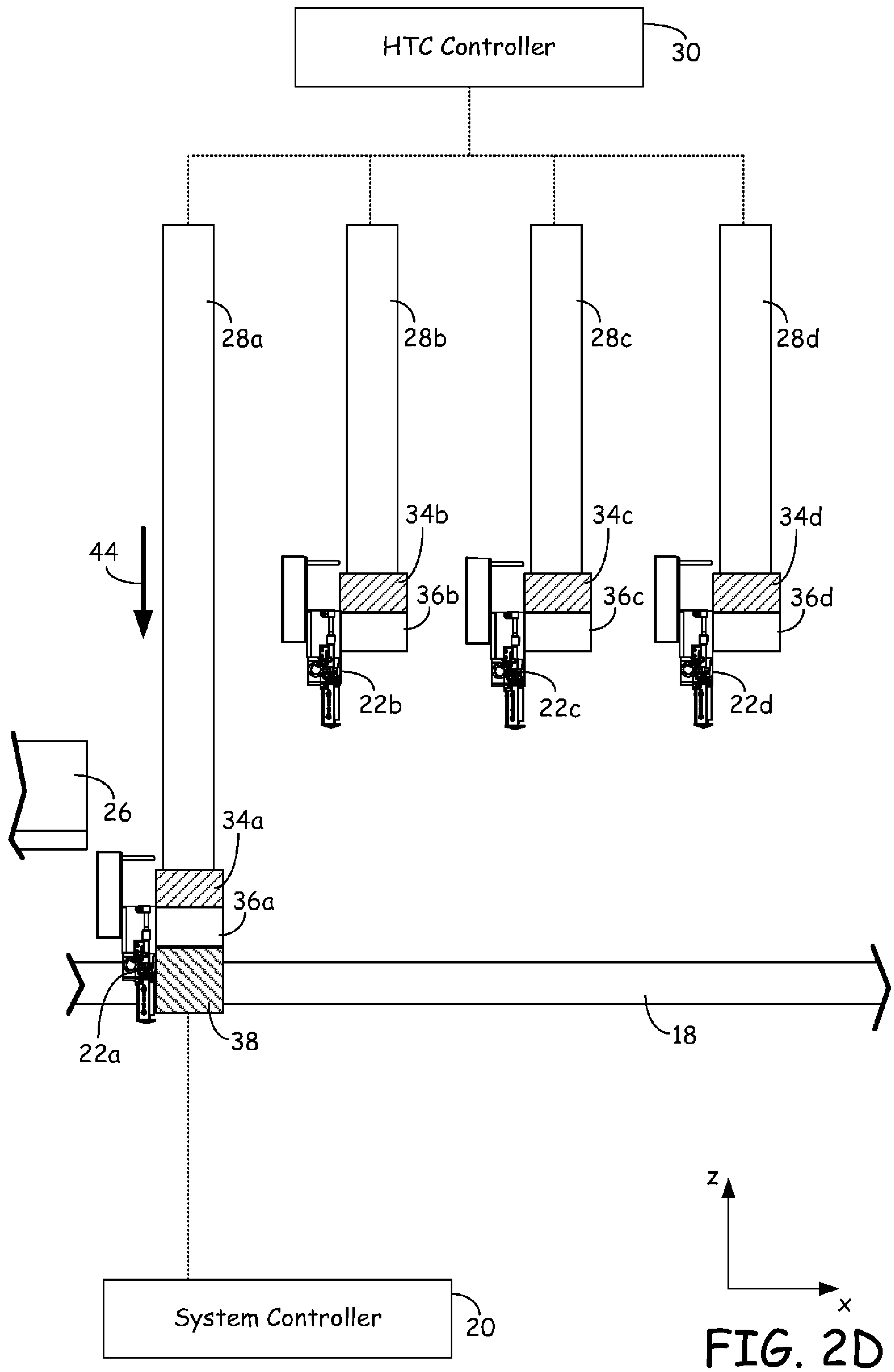
42
38
18
z
x
System Controller
20

FIG. 2C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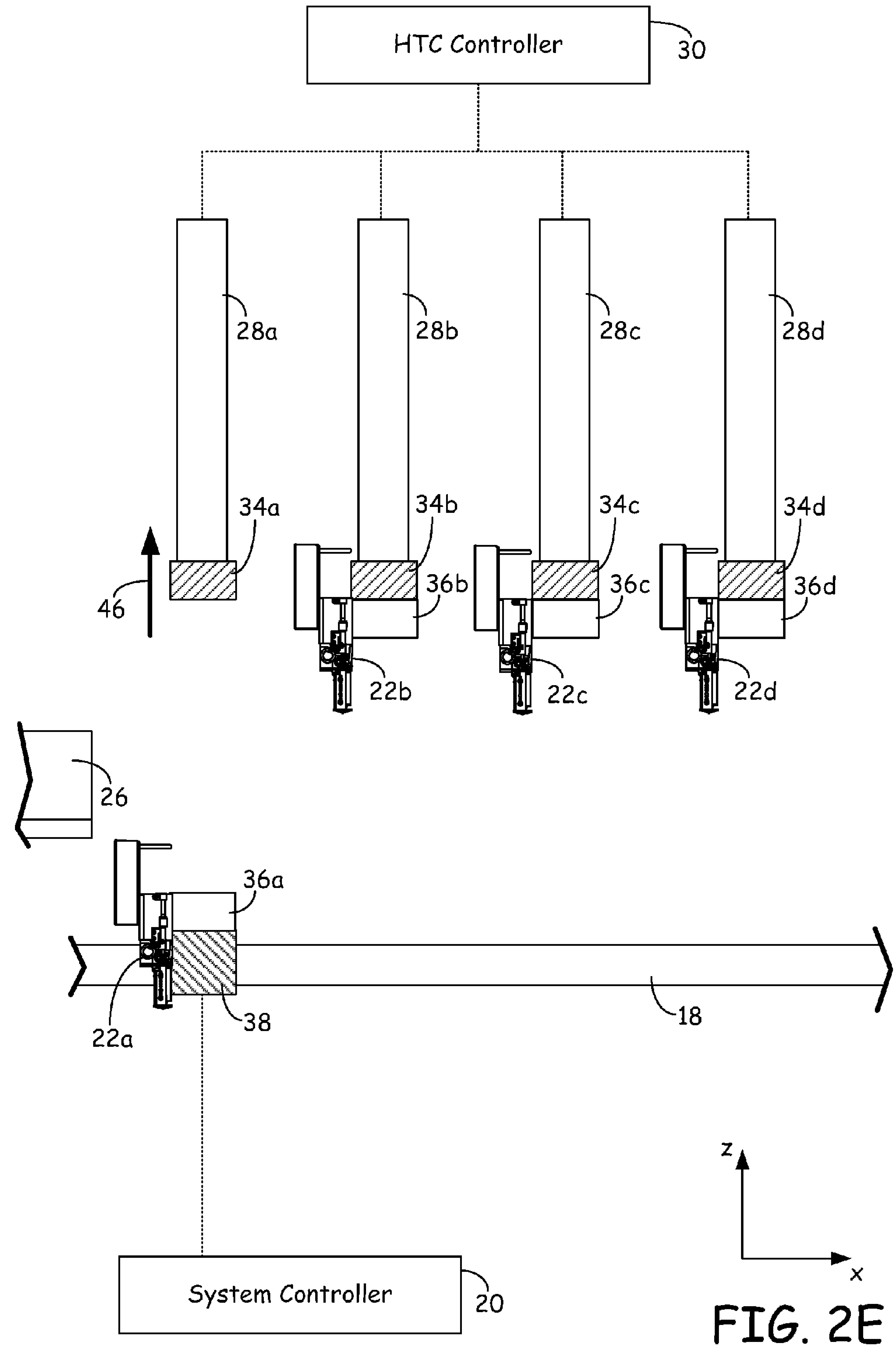
34a
36a
22a
38
18
z
x
System Controller
20

FIG. 2D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34c
34d
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22c
22d
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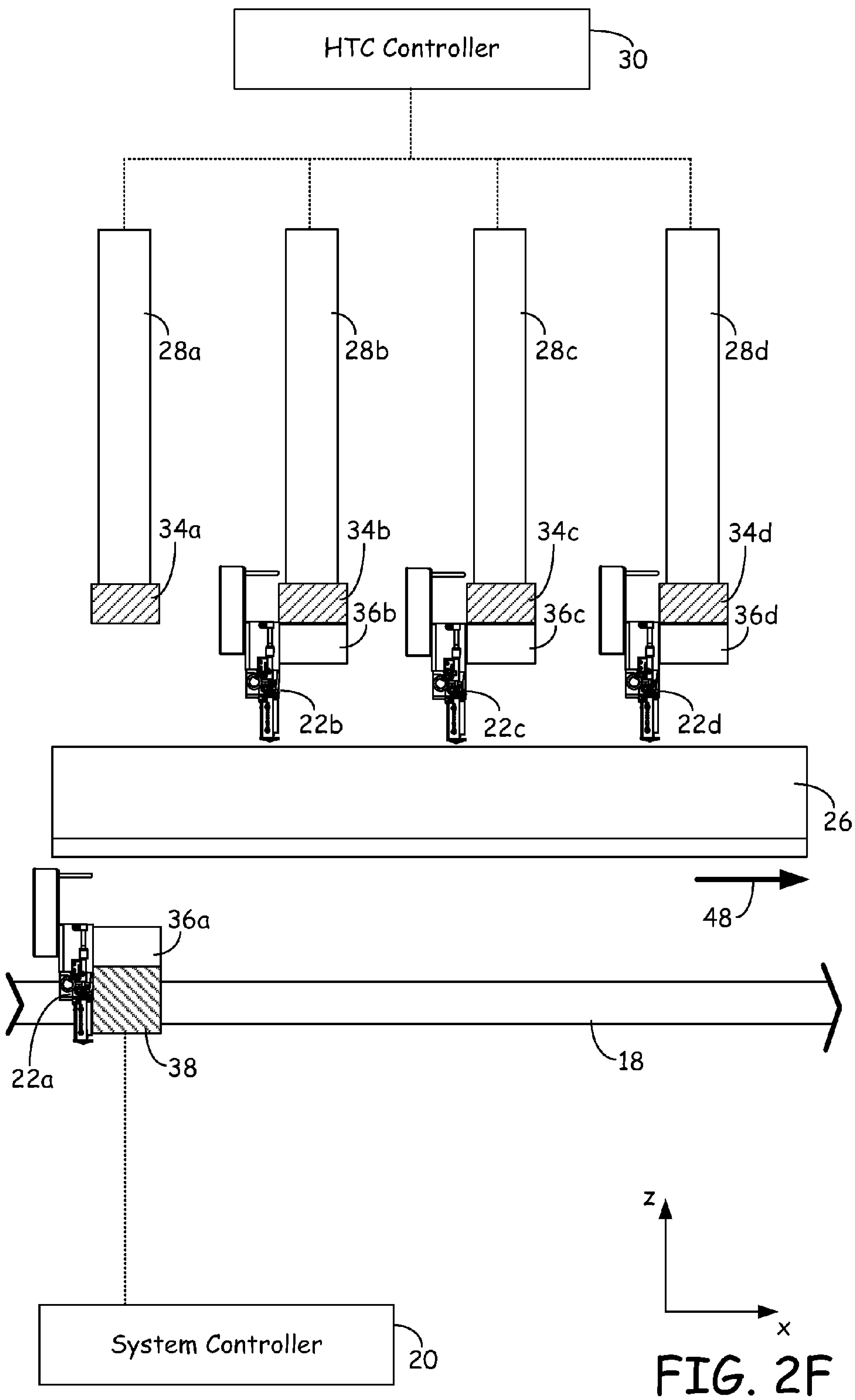
36a
22a
38
18
z
x
System Controller
20

FIG. 2E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34c
34d
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22d
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36a
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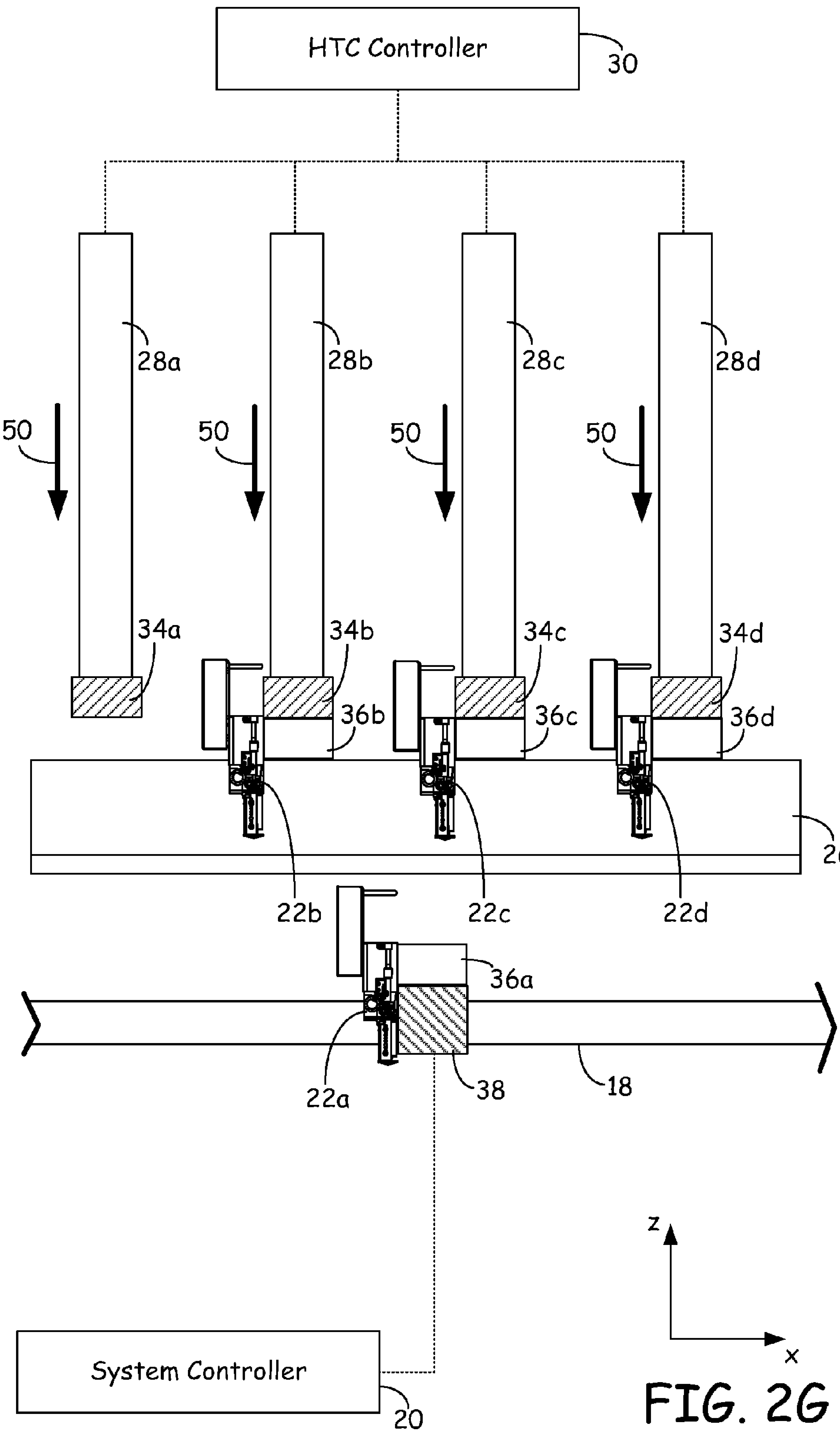
18
z
x
System Controller
20

FIG. 2F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22b
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22d
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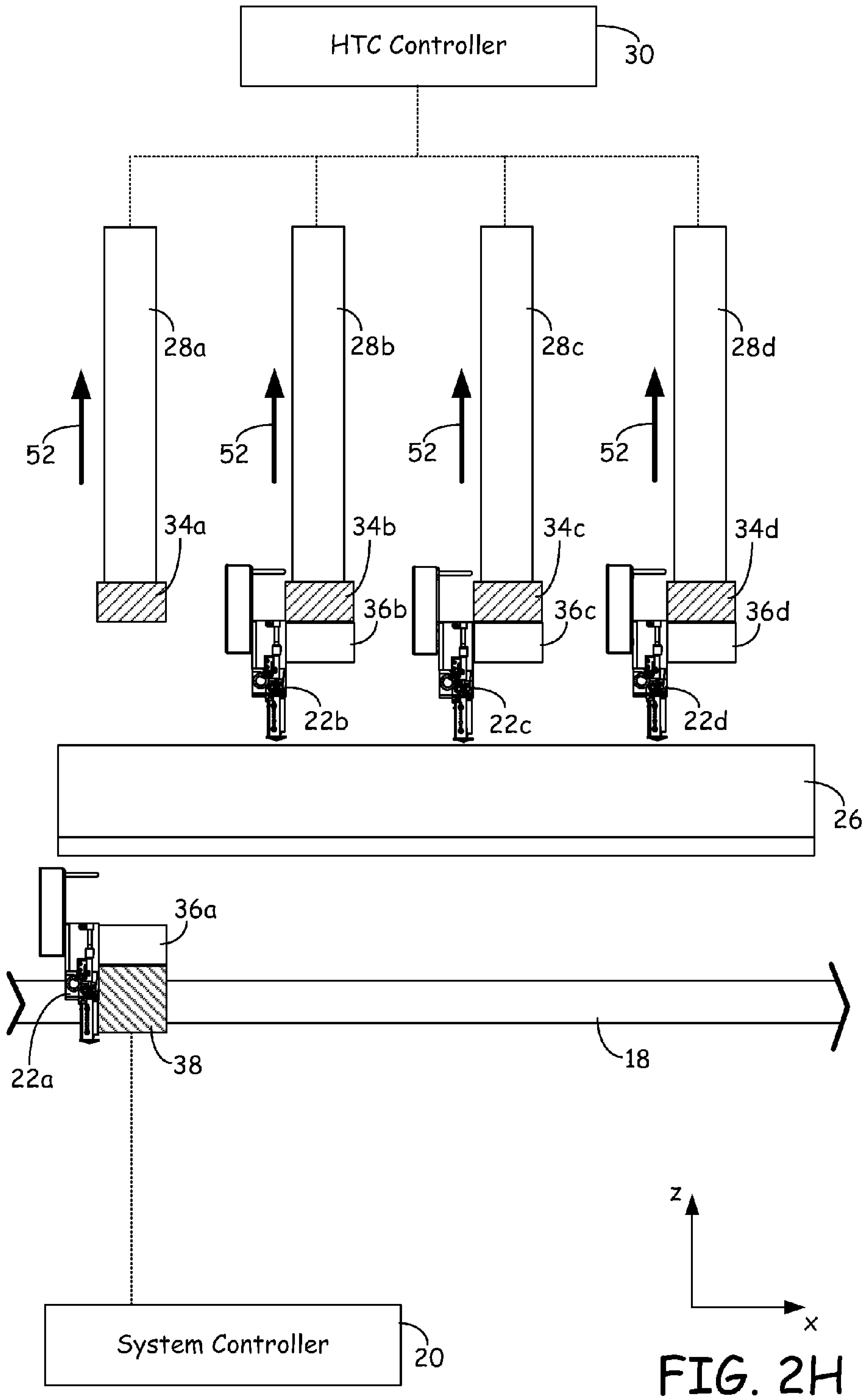
22a
38
18
z
x
System Controller
20

FIG. 2G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22b
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22a
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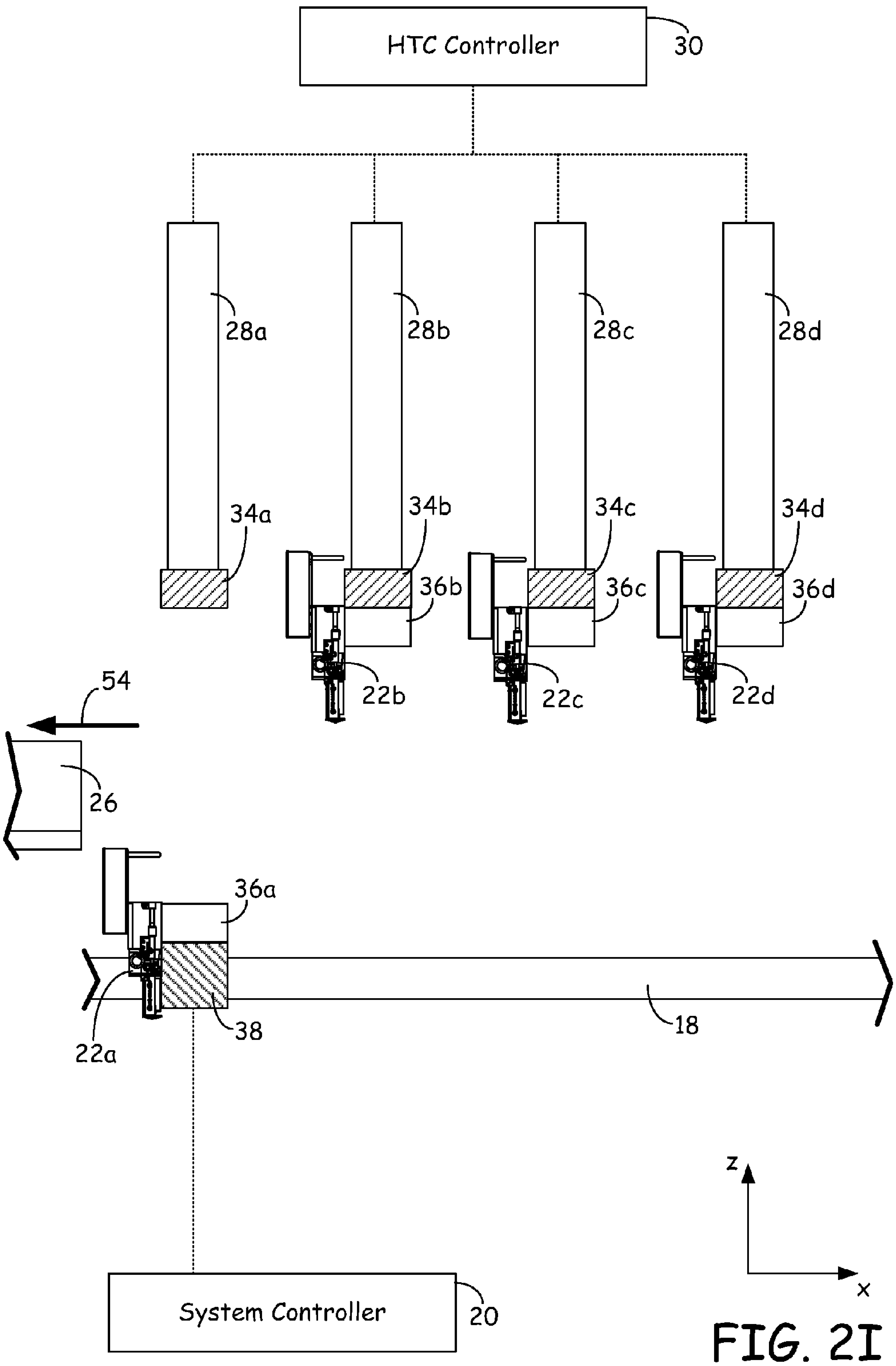
18
System Controller
20
z
x

FIG. 2H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18
z
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System Controller
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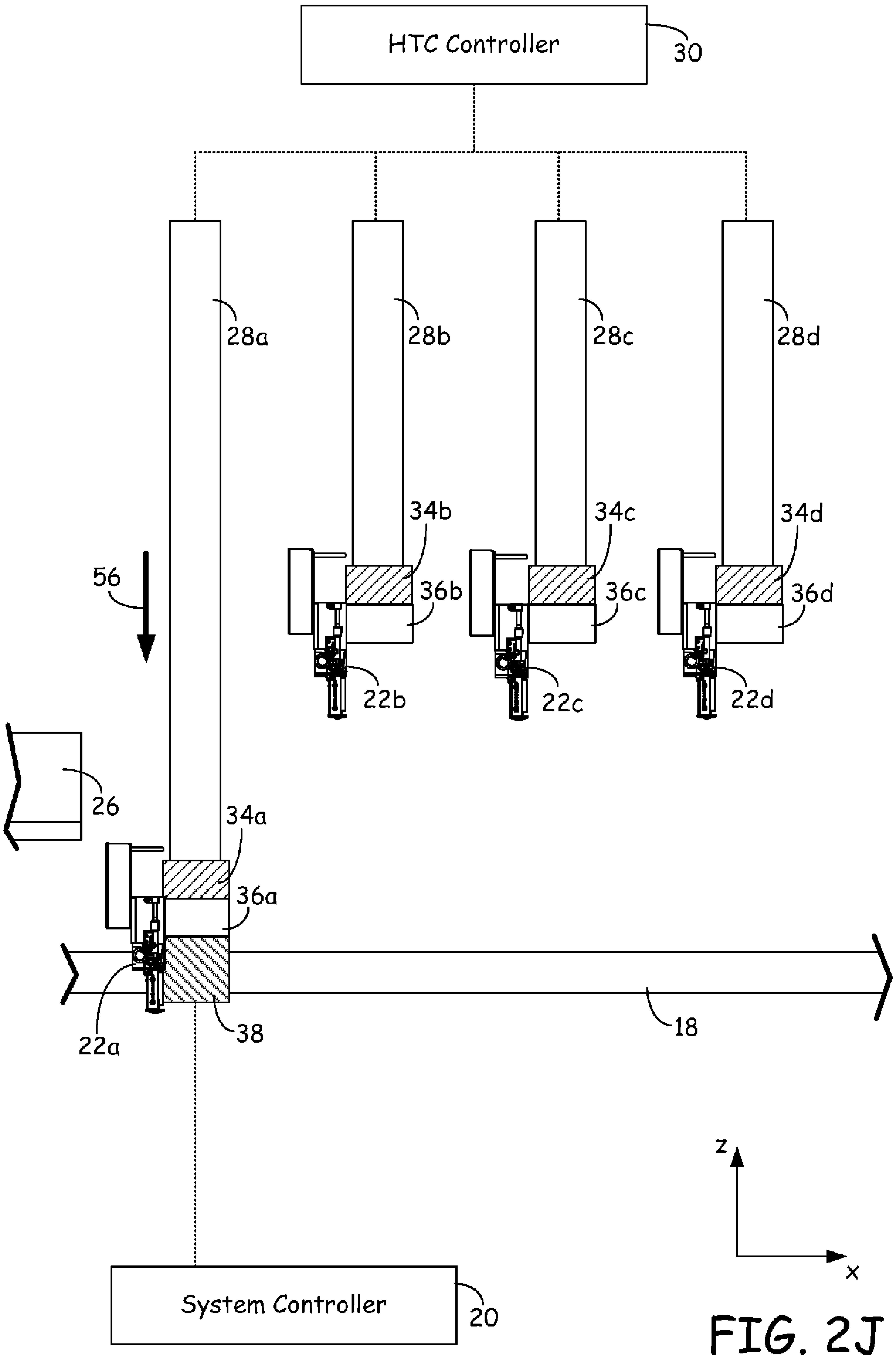
FIG. 2I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36c
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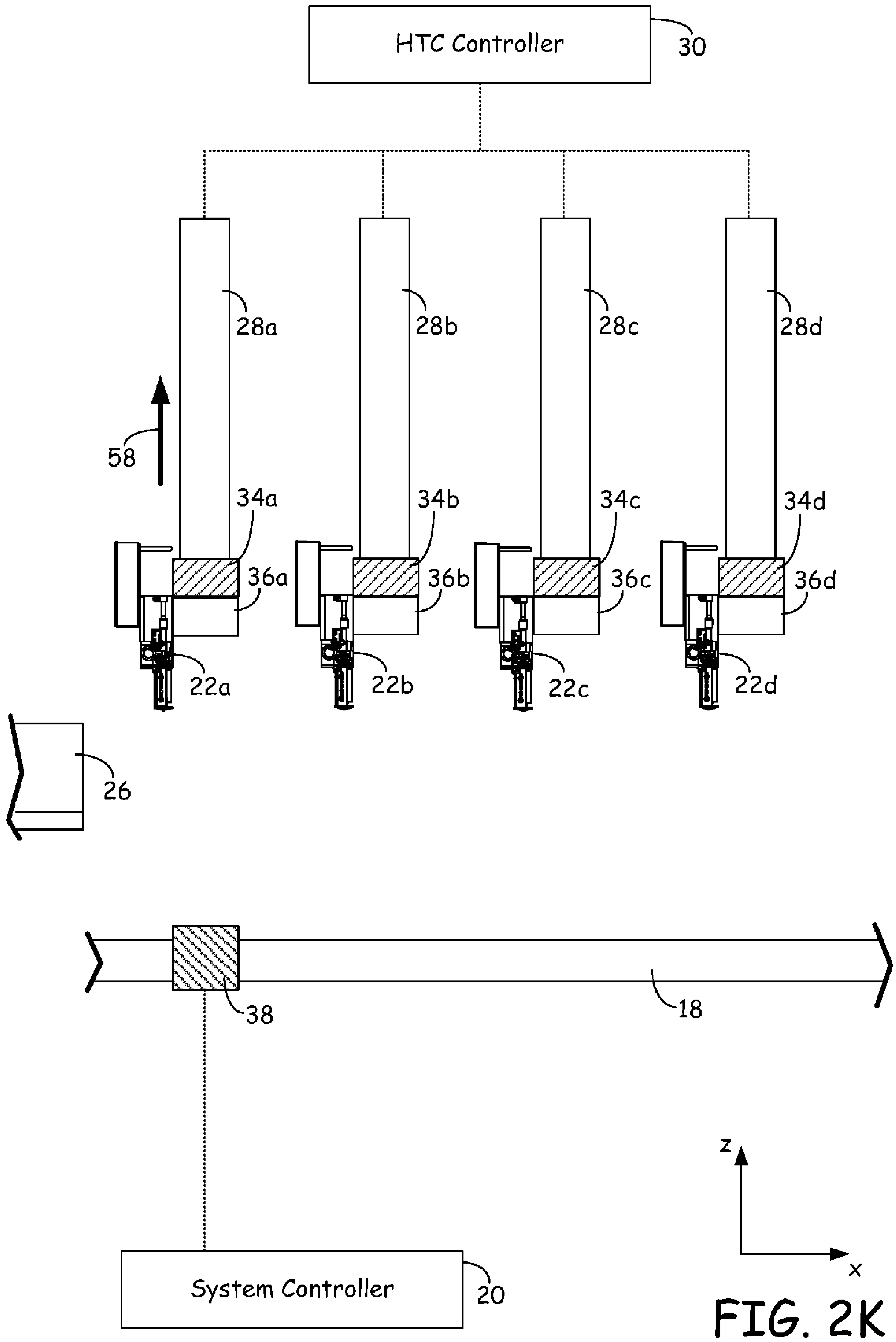
22d
26
34a
36a
22a
38
18
z
x
System Controller
20

FIG. 2J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36c
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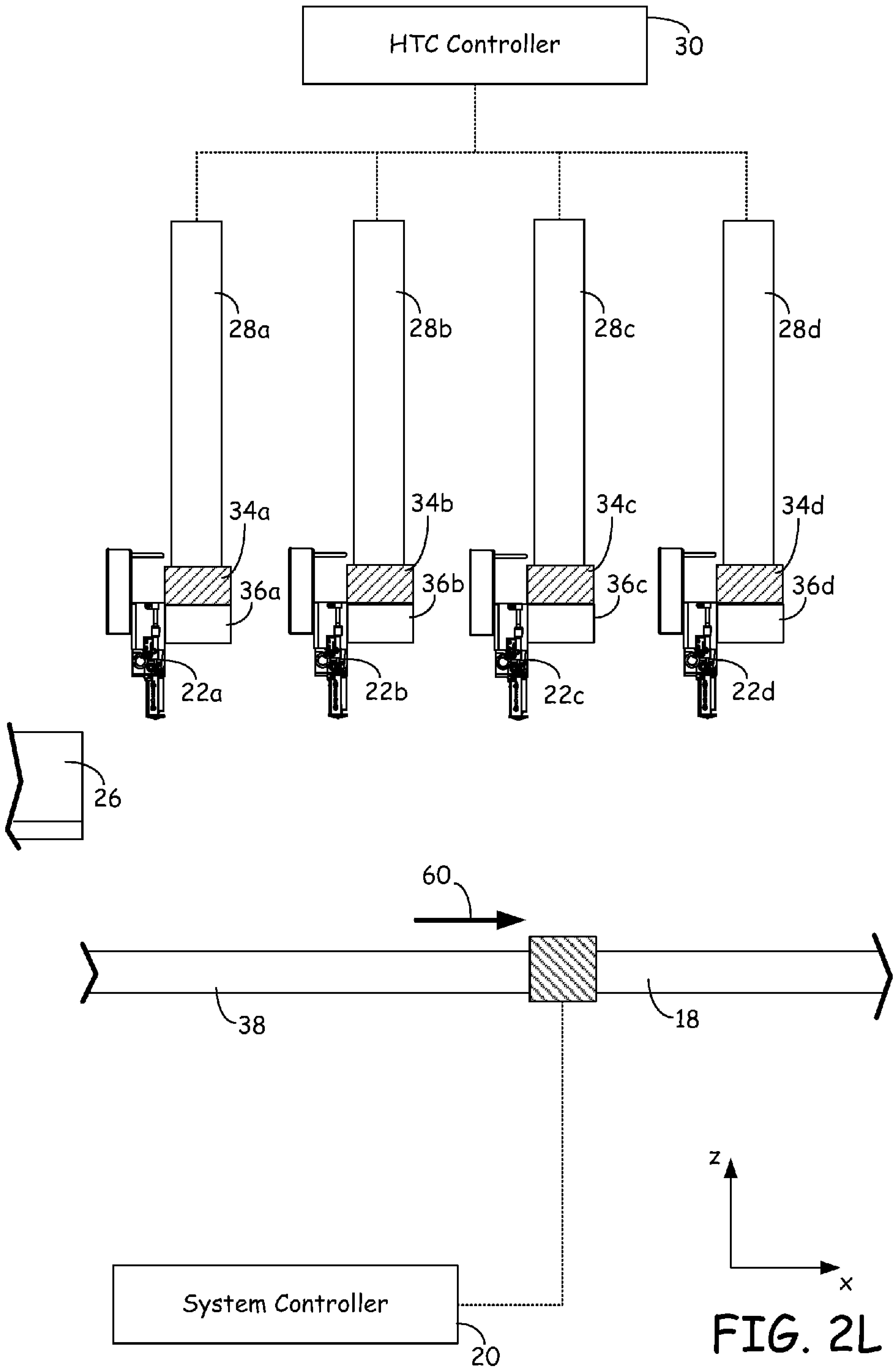
22a
22b
22c
22d
26
38
18
System Controller
20
z
x

FIG. 2K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System Controller
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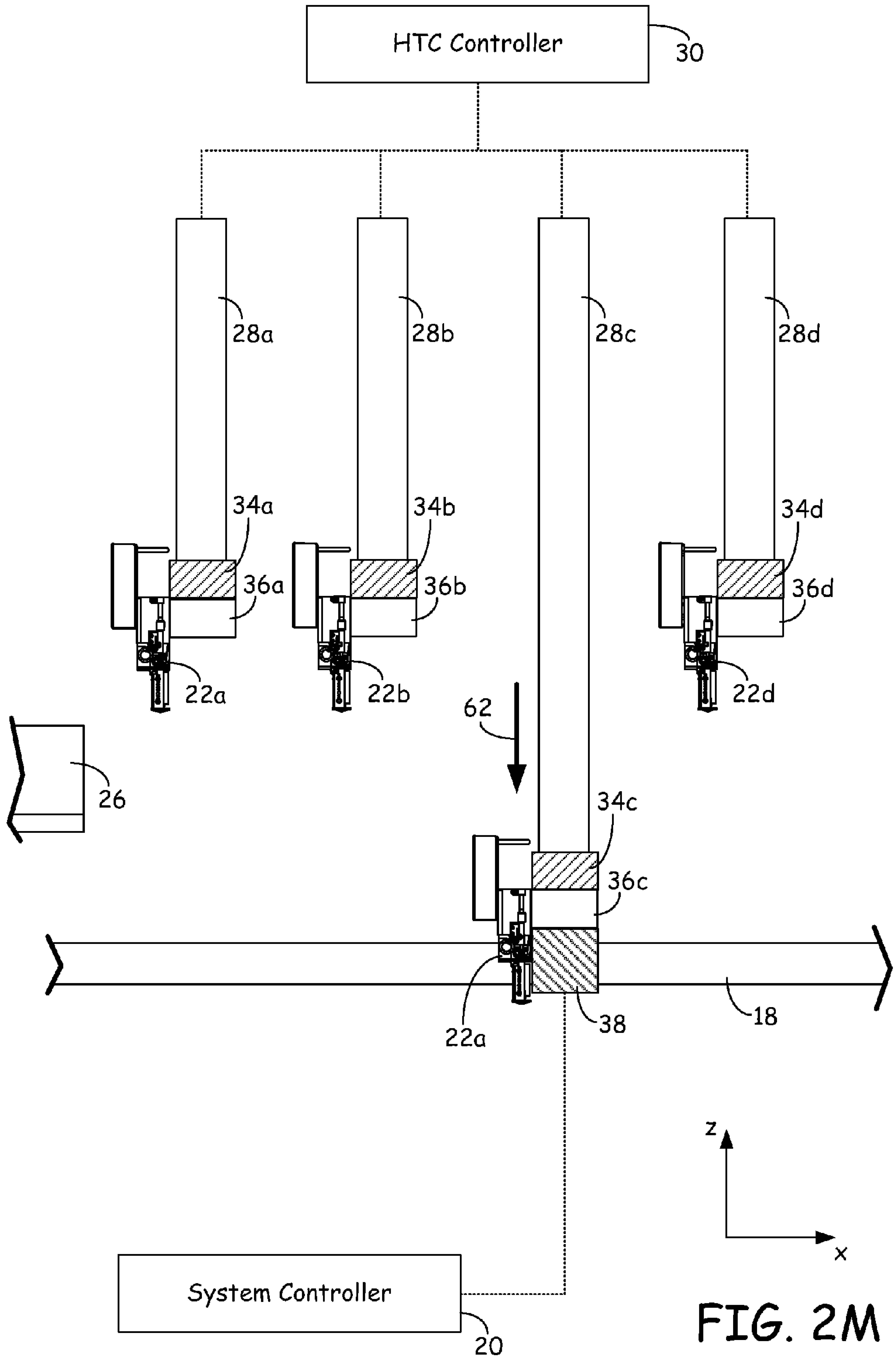
FIG. 2L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System Controller
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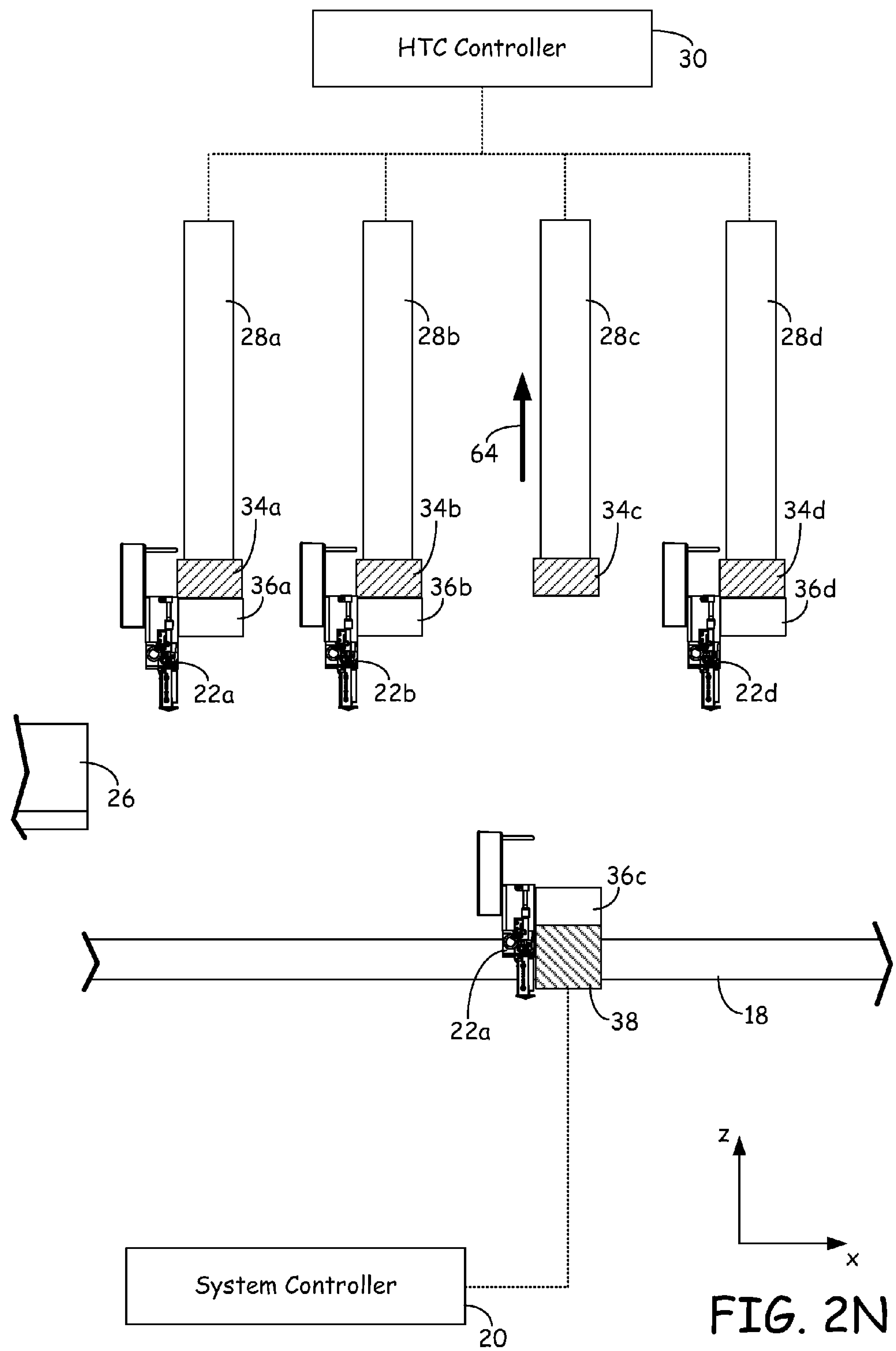
FIG. 2M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System Controller
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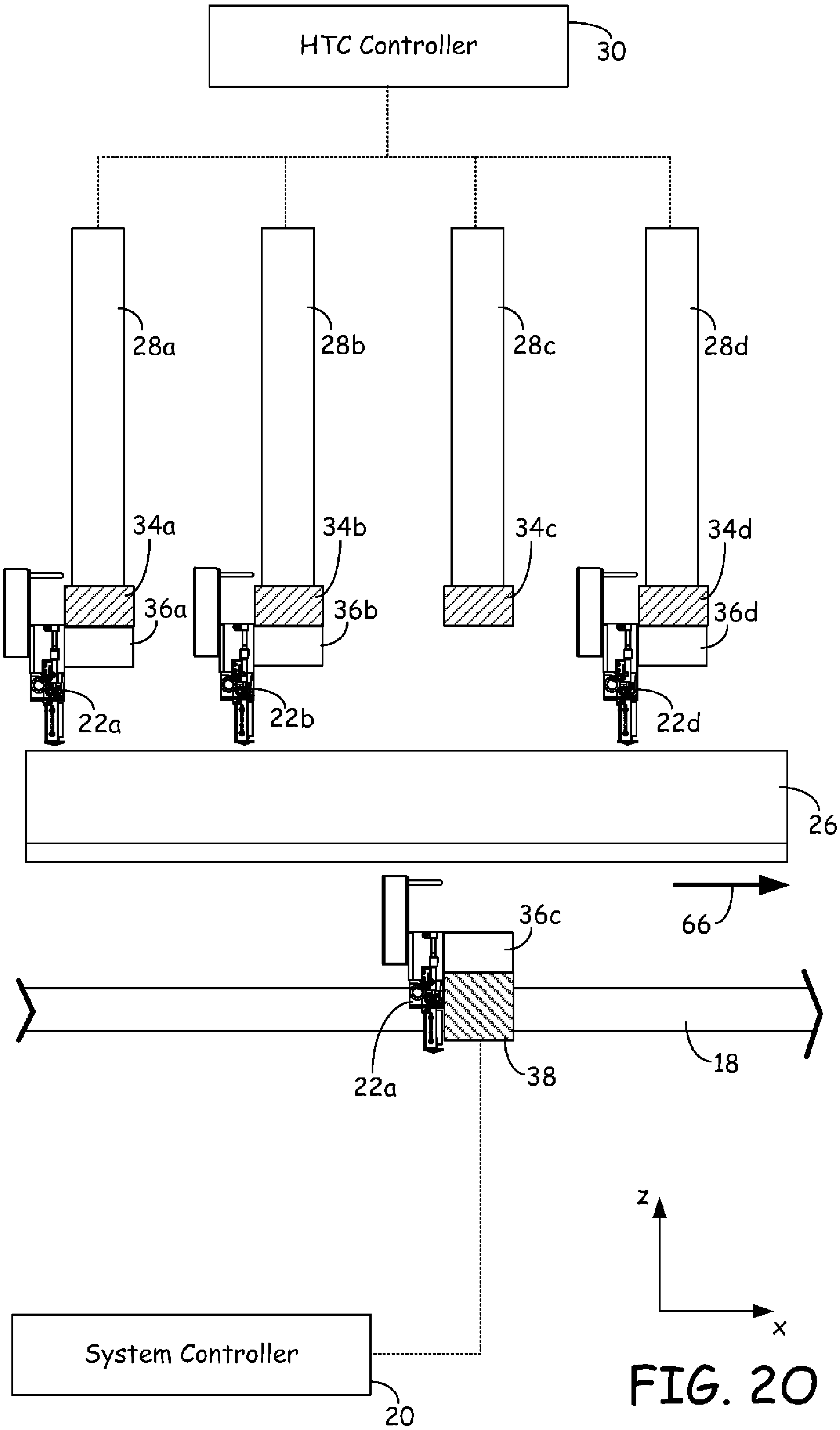
FIG. 2N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System Controller
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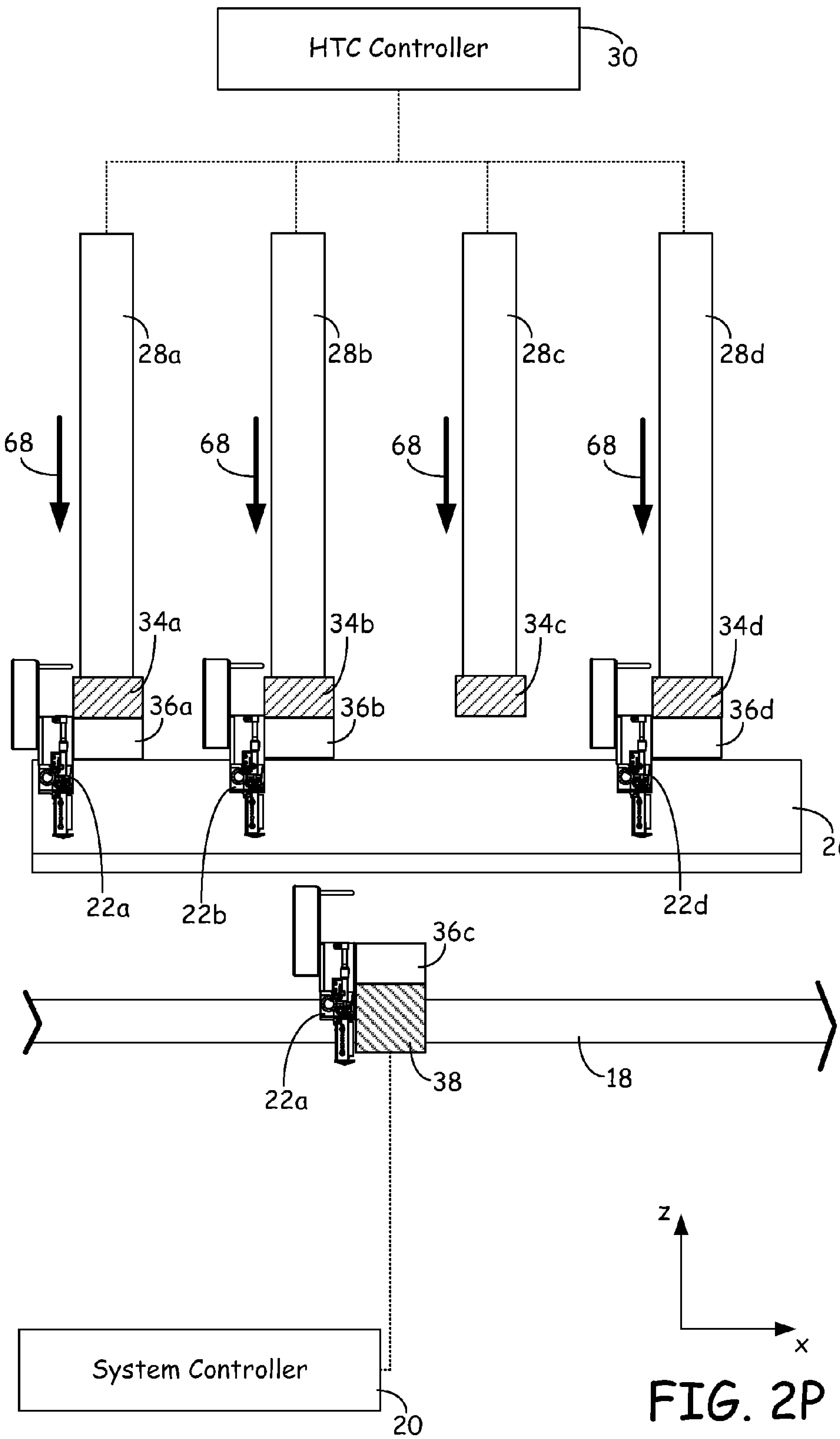
FIG. 20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System Controller
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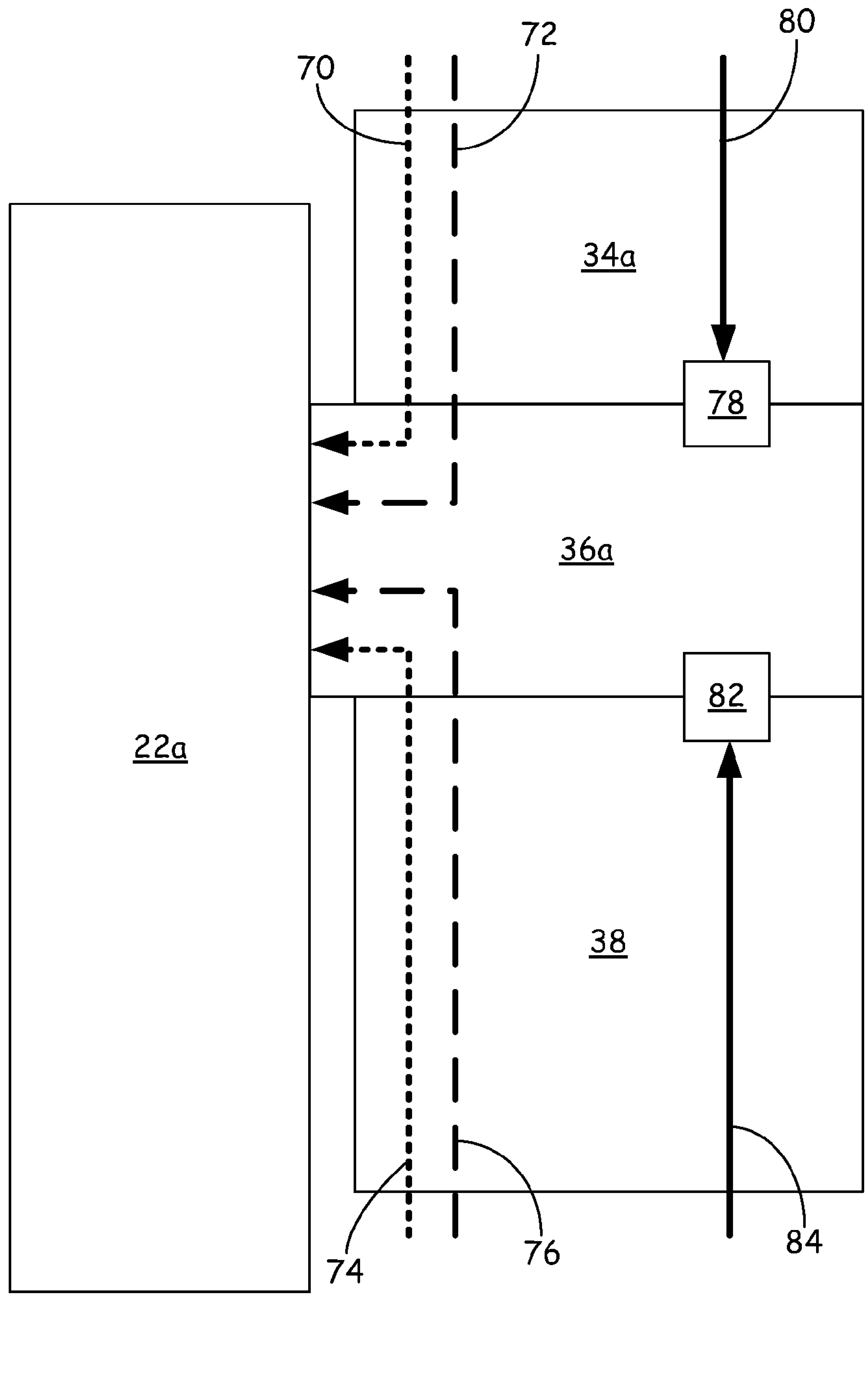
FIG. 2P



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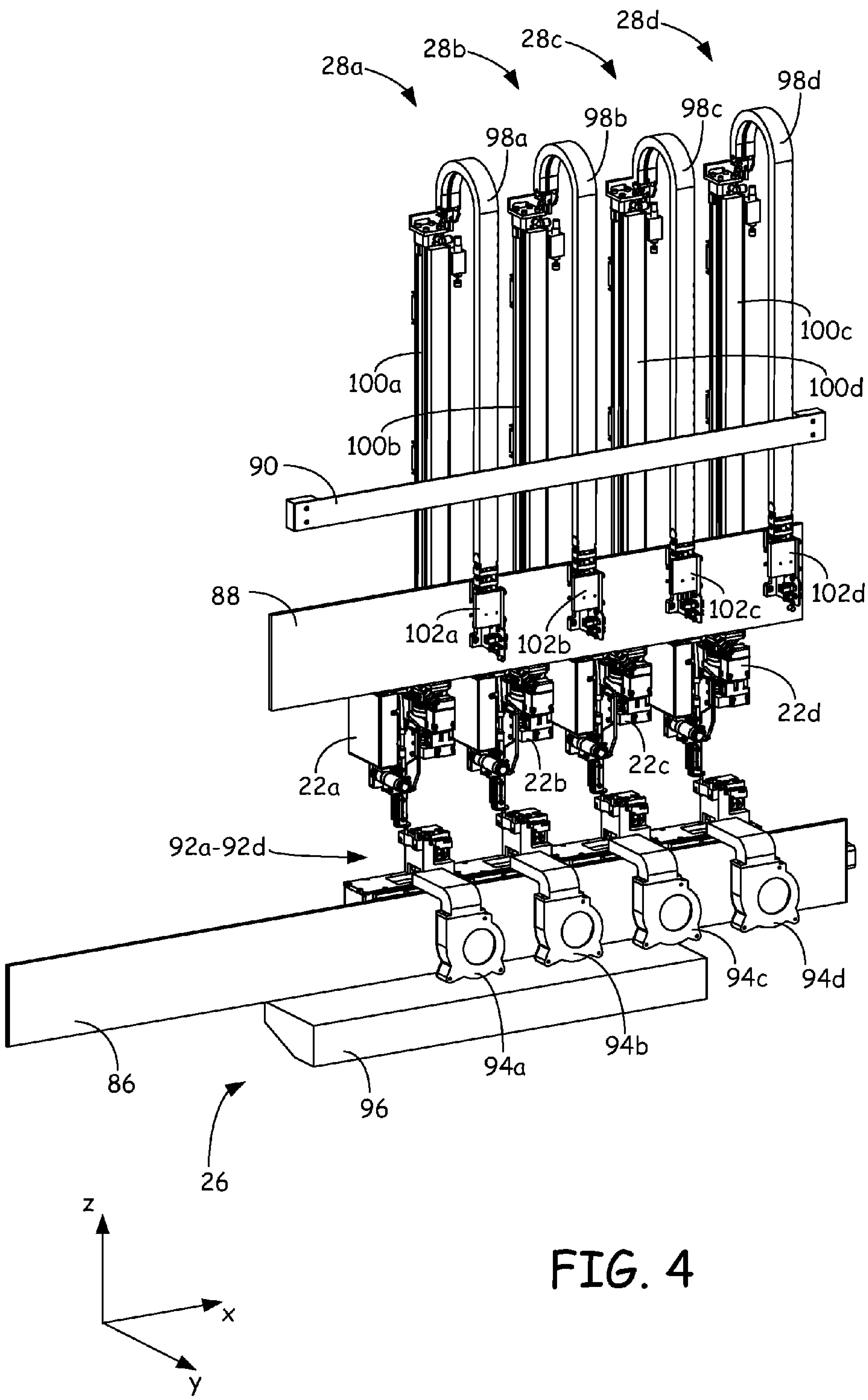
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102d
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26
z
x
y

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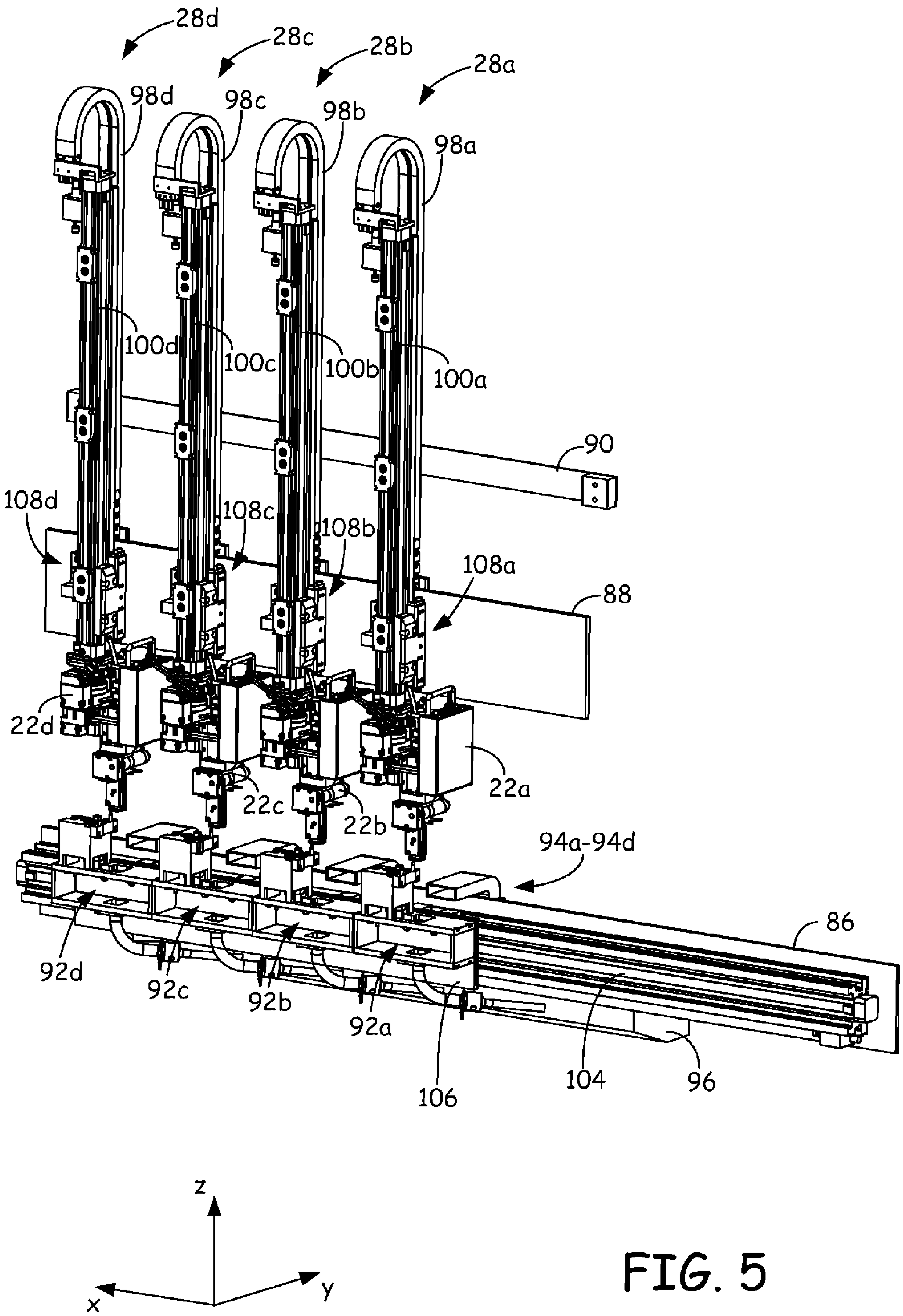
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z
x
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FIG. 5

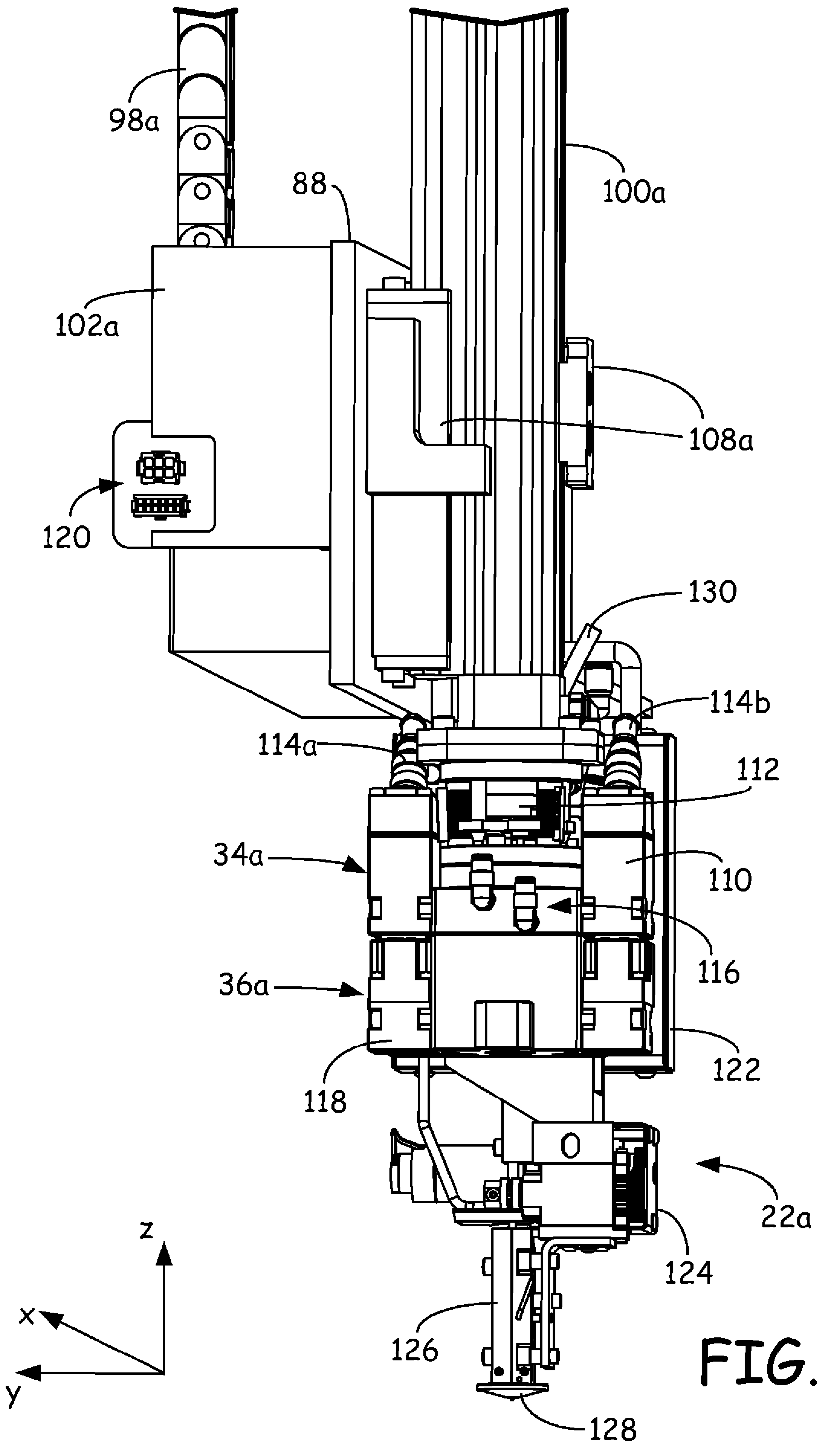
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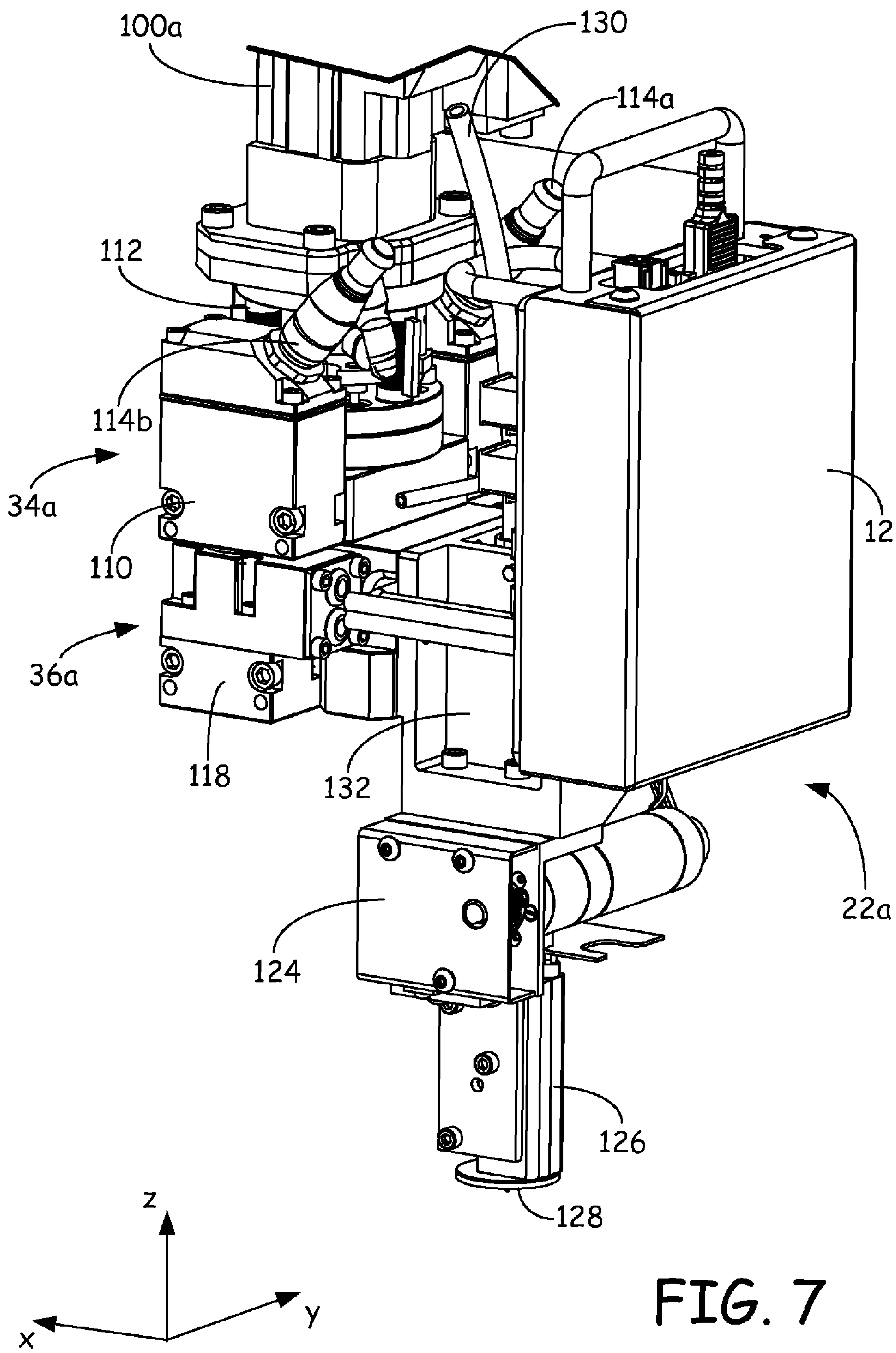
FIG. 6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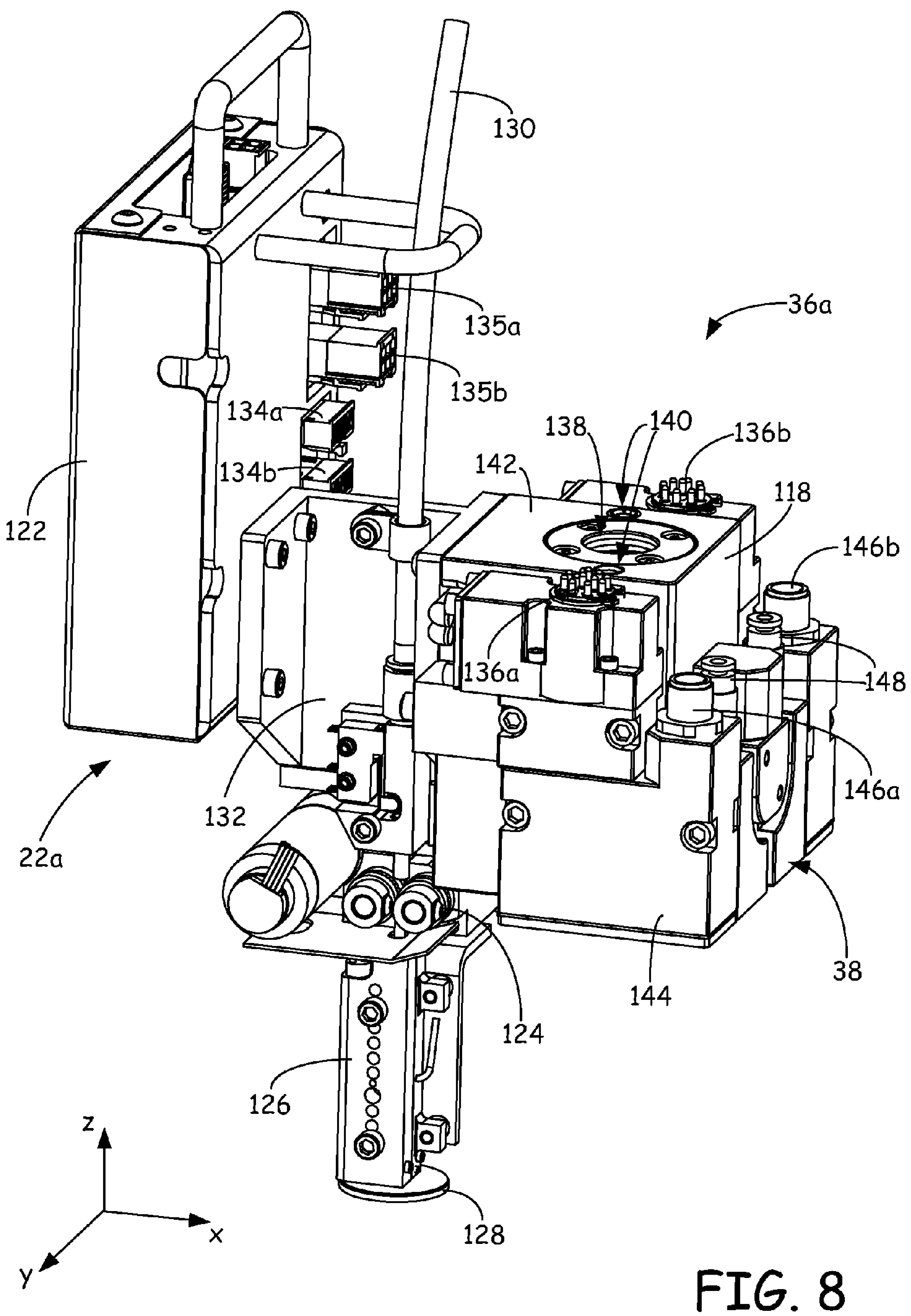
x

FIG. 7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z
x
y
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FIG. 8

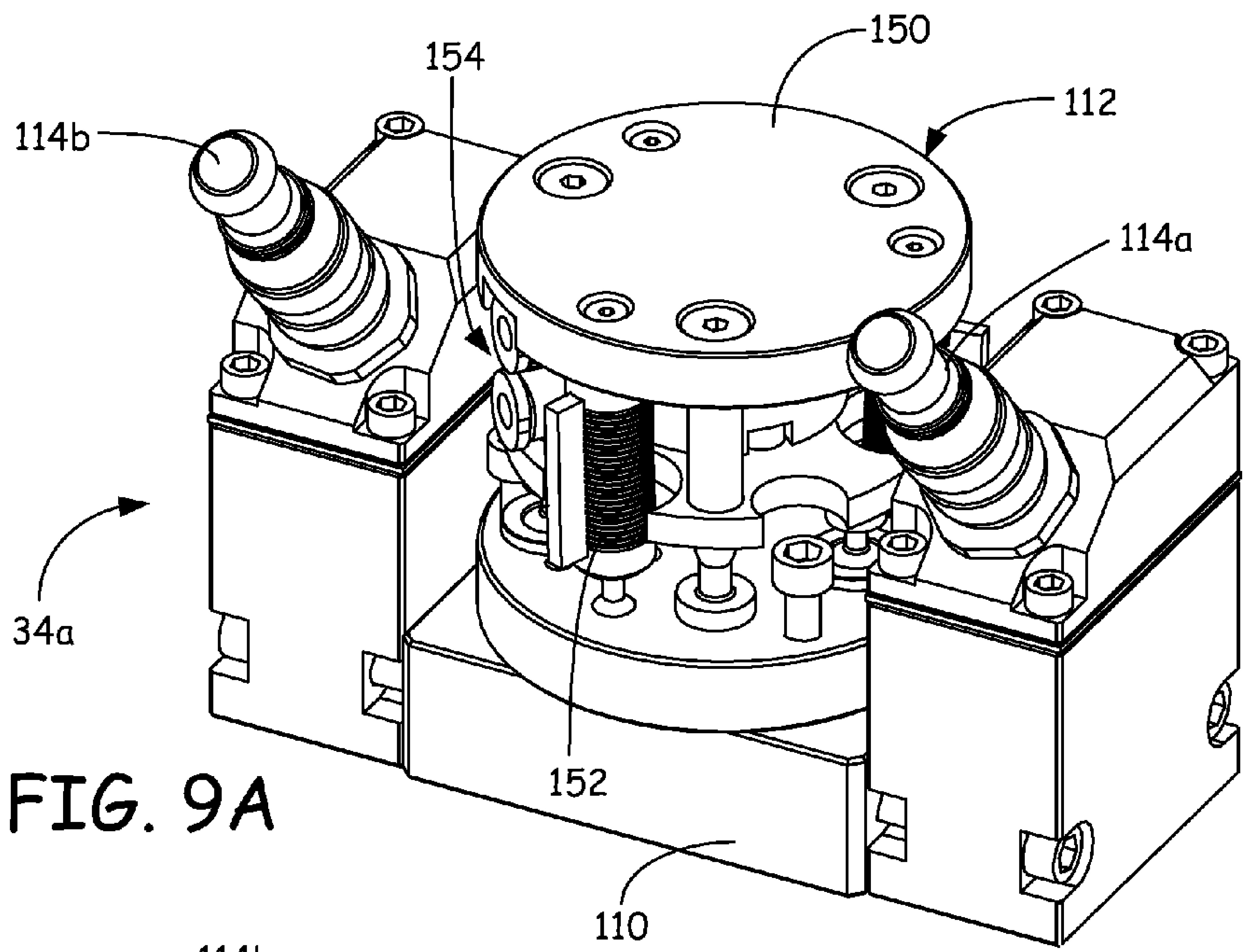
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FIG. 9A

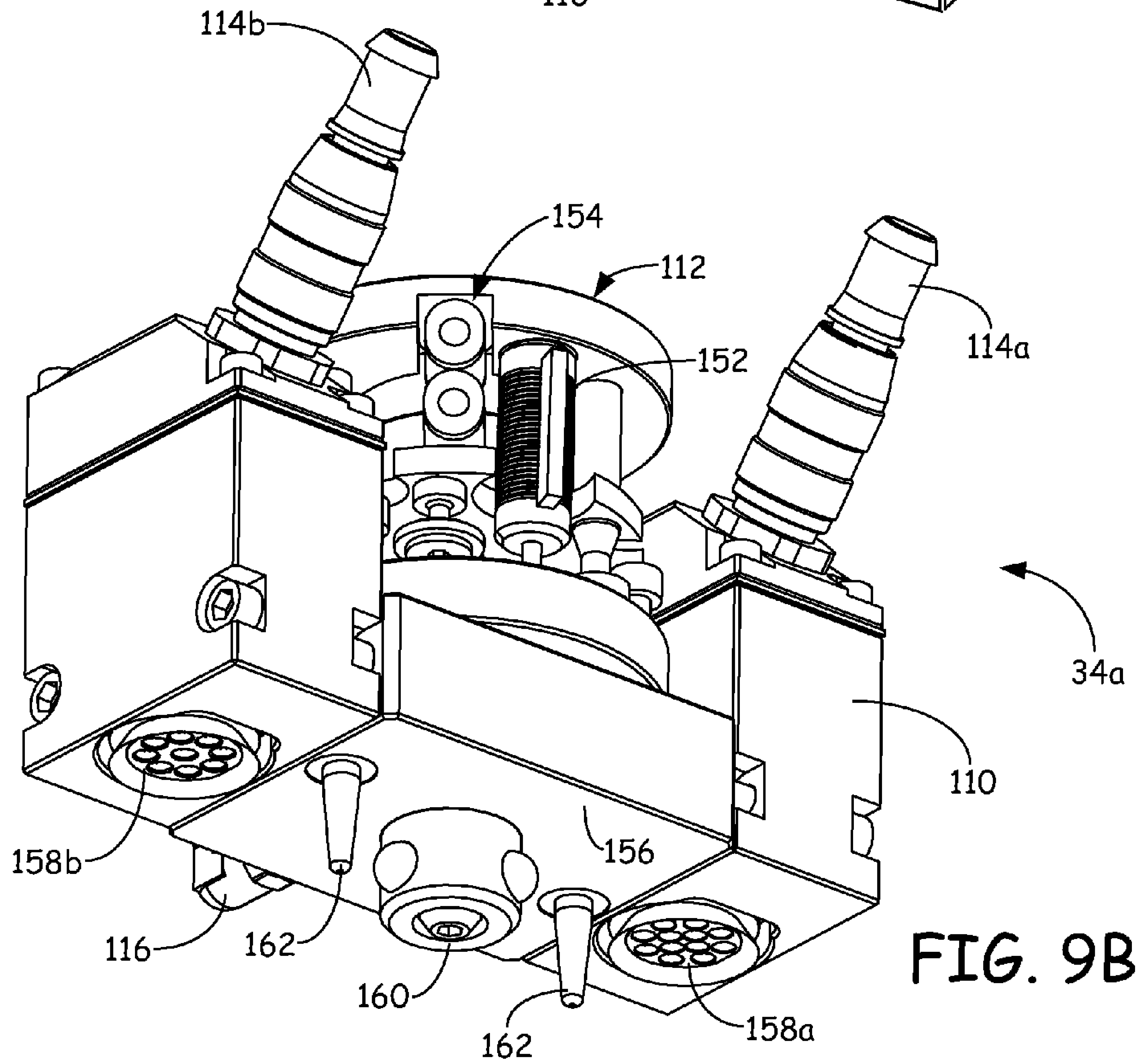
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FIG. 9B

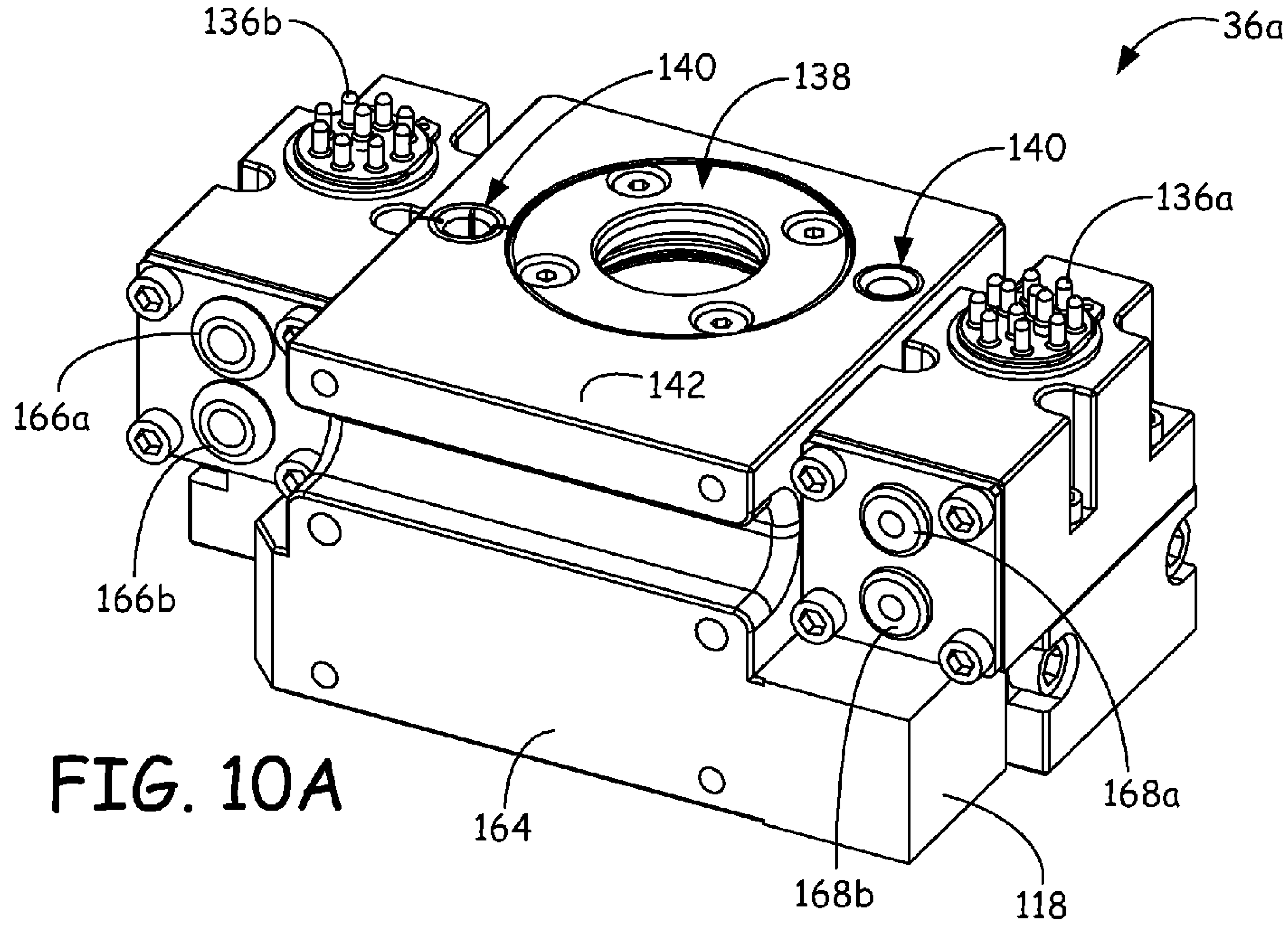


FIG. 10A

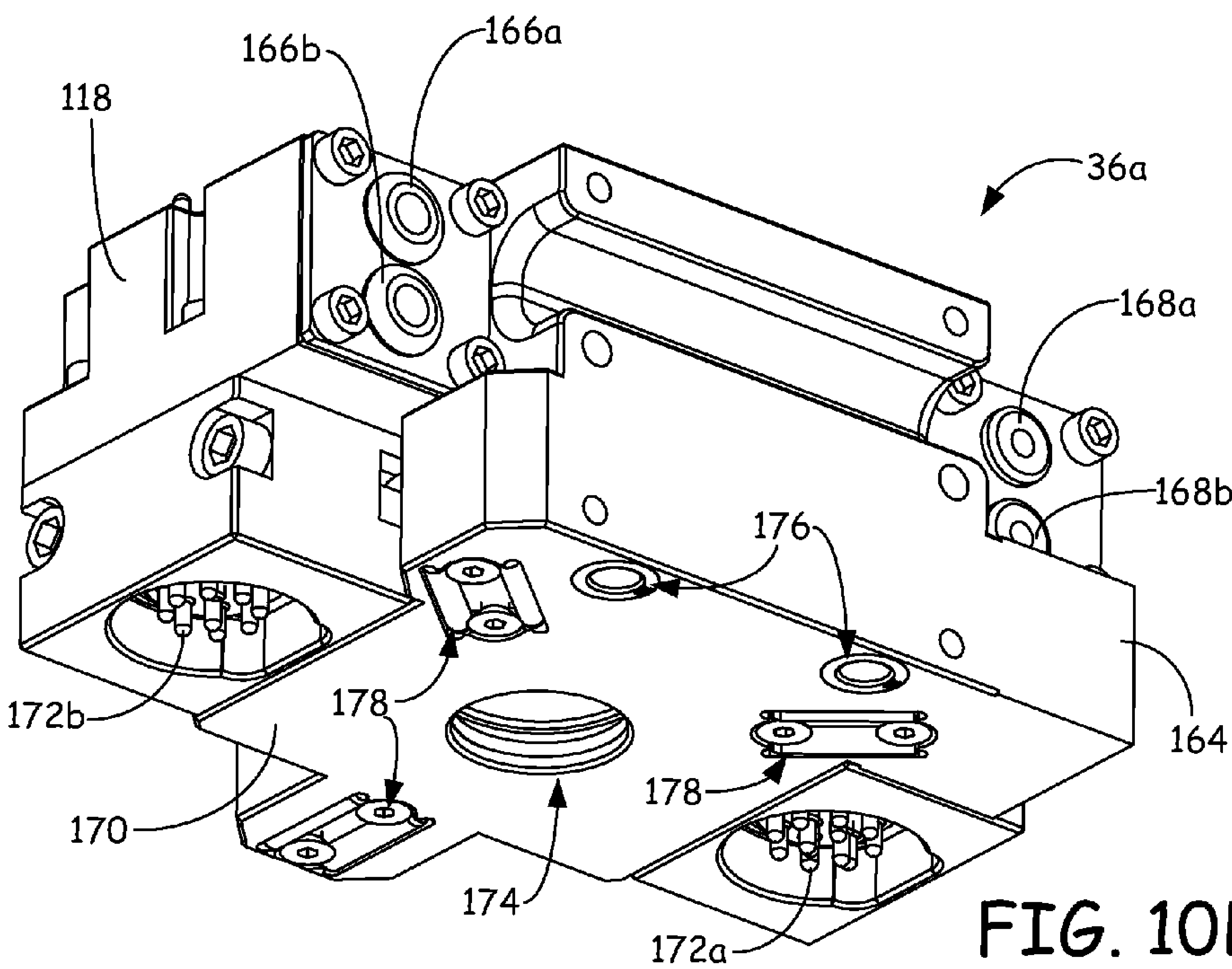


FIG. 10B

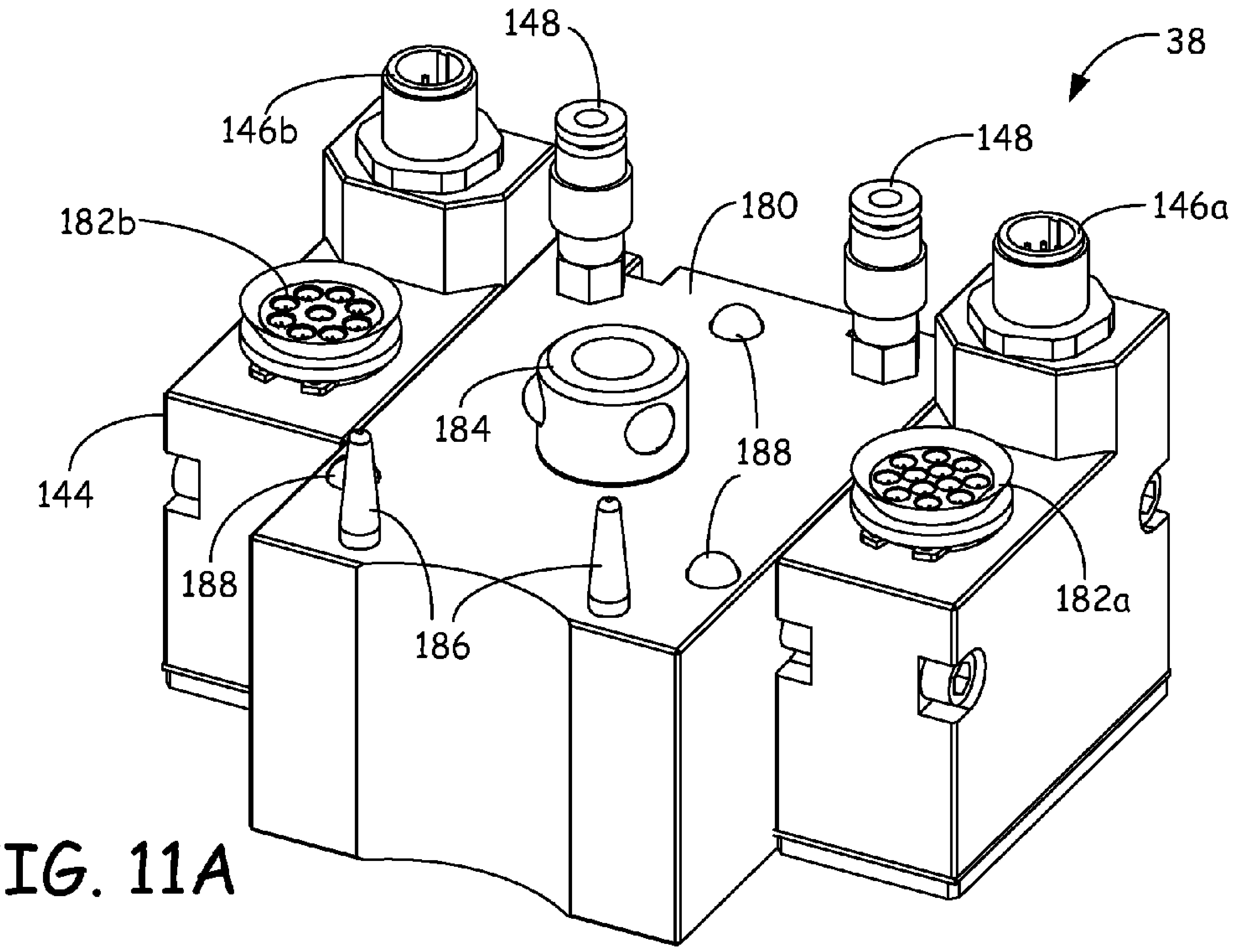


FIG. 11A

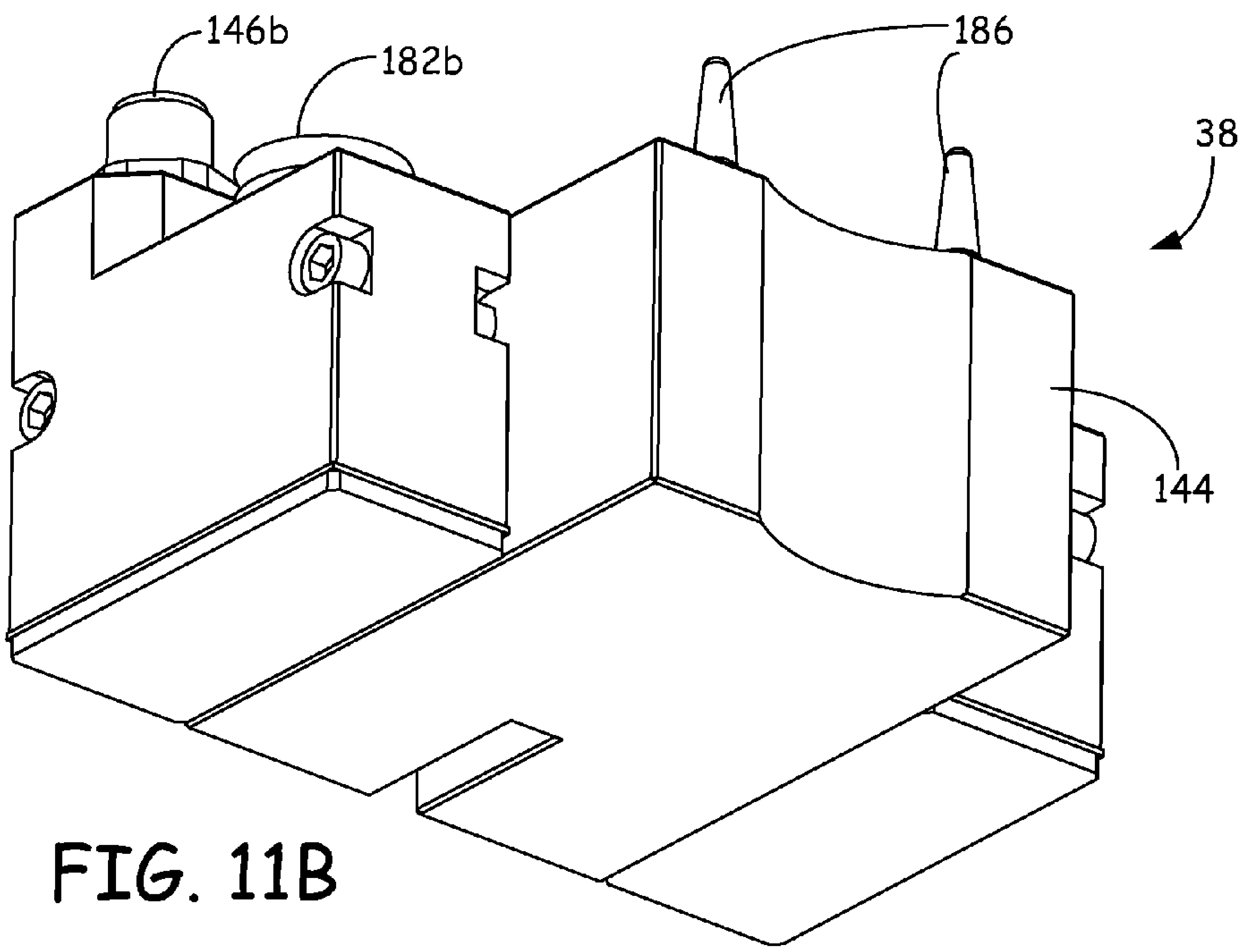
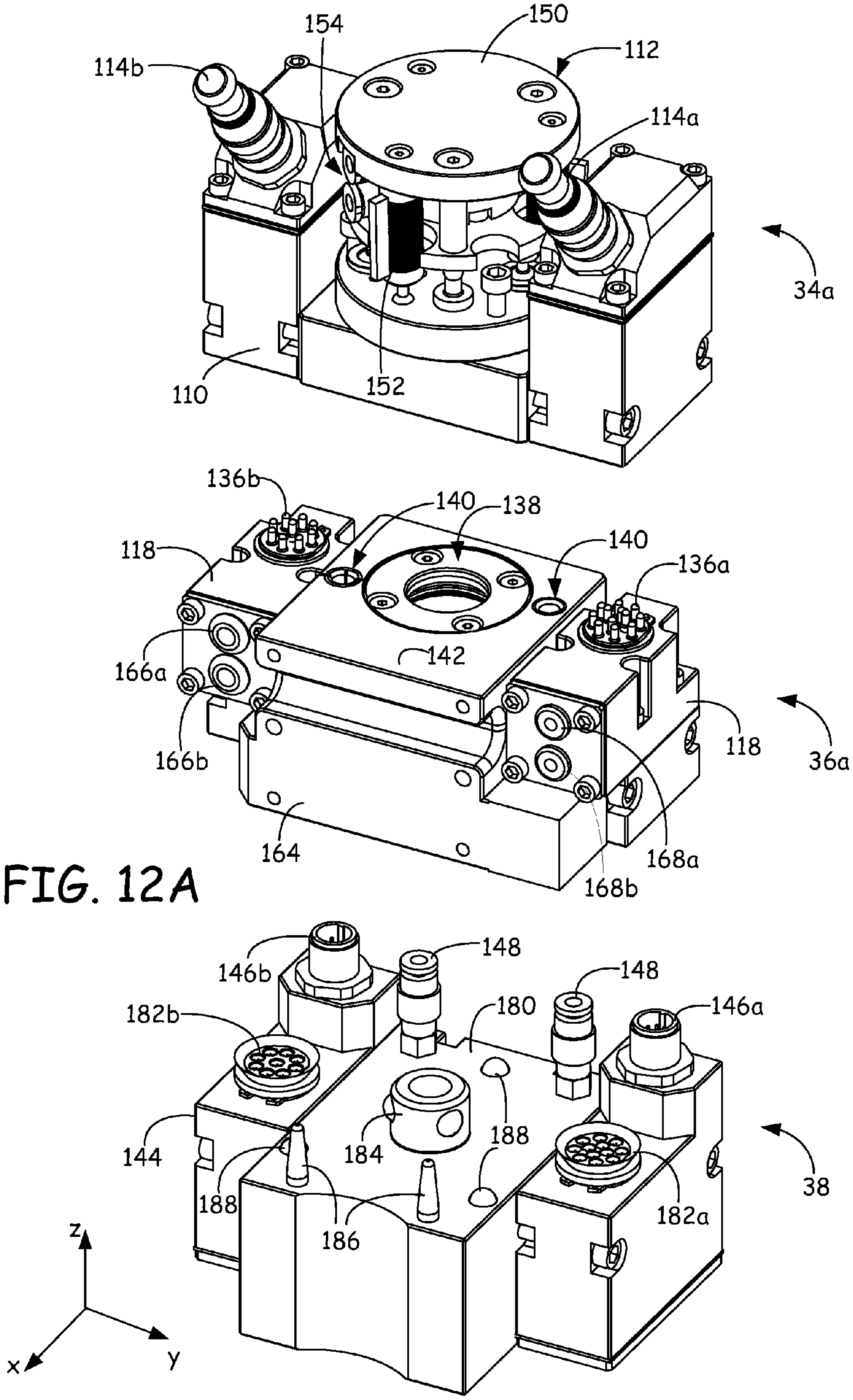


FIG. 11B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186
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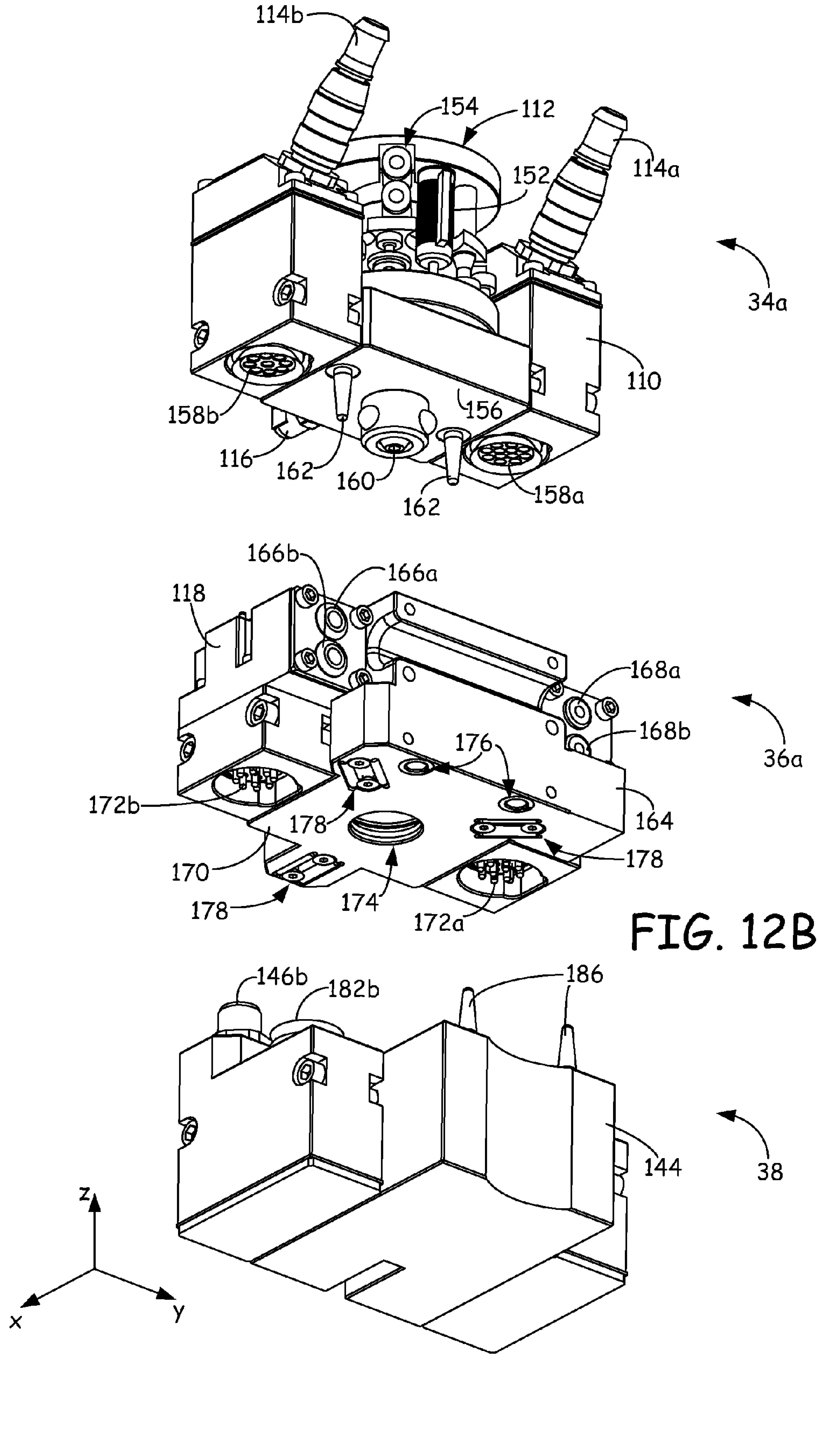
z
x
y

FIG. 12A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36a
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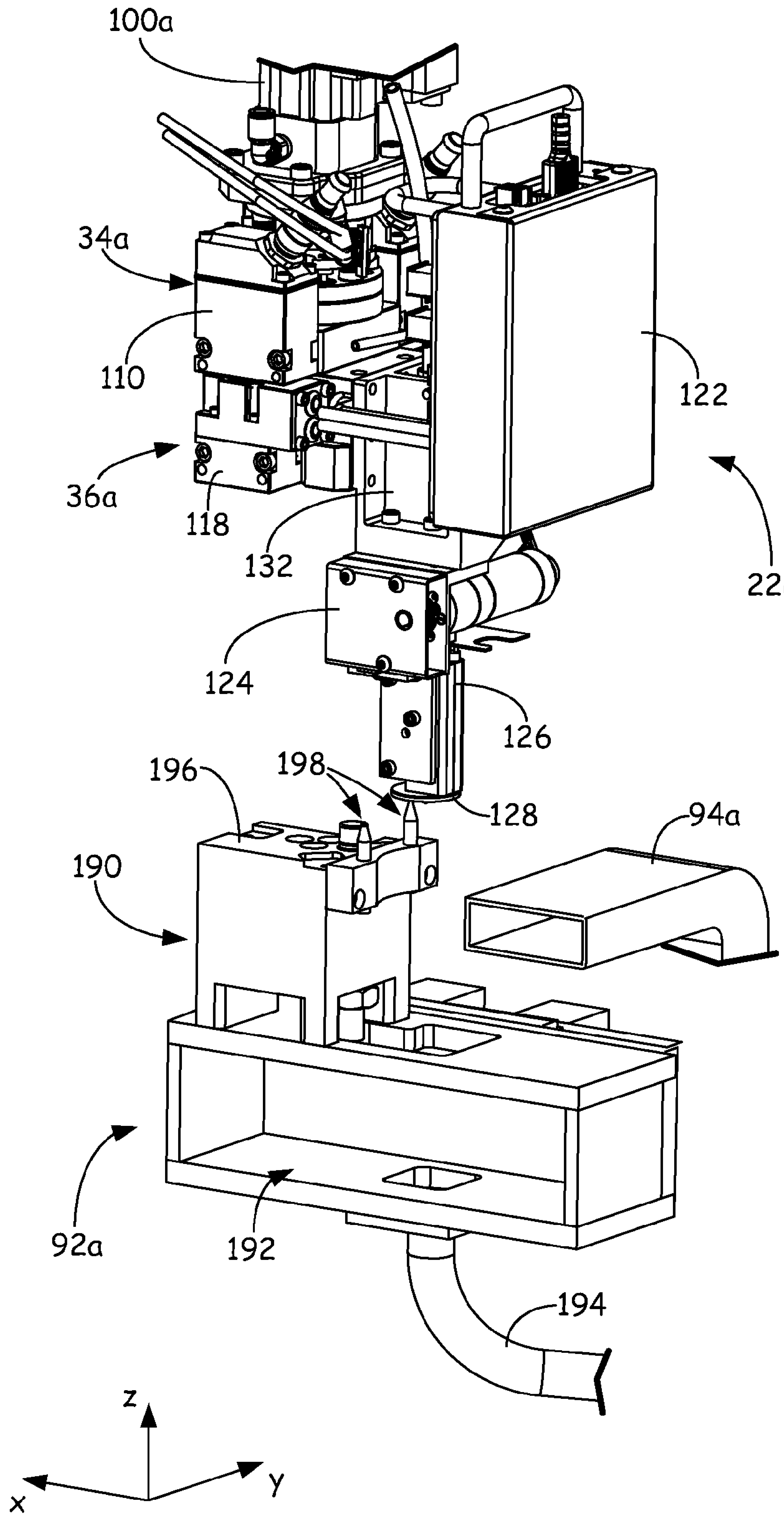
z
x
y

FIG. 12B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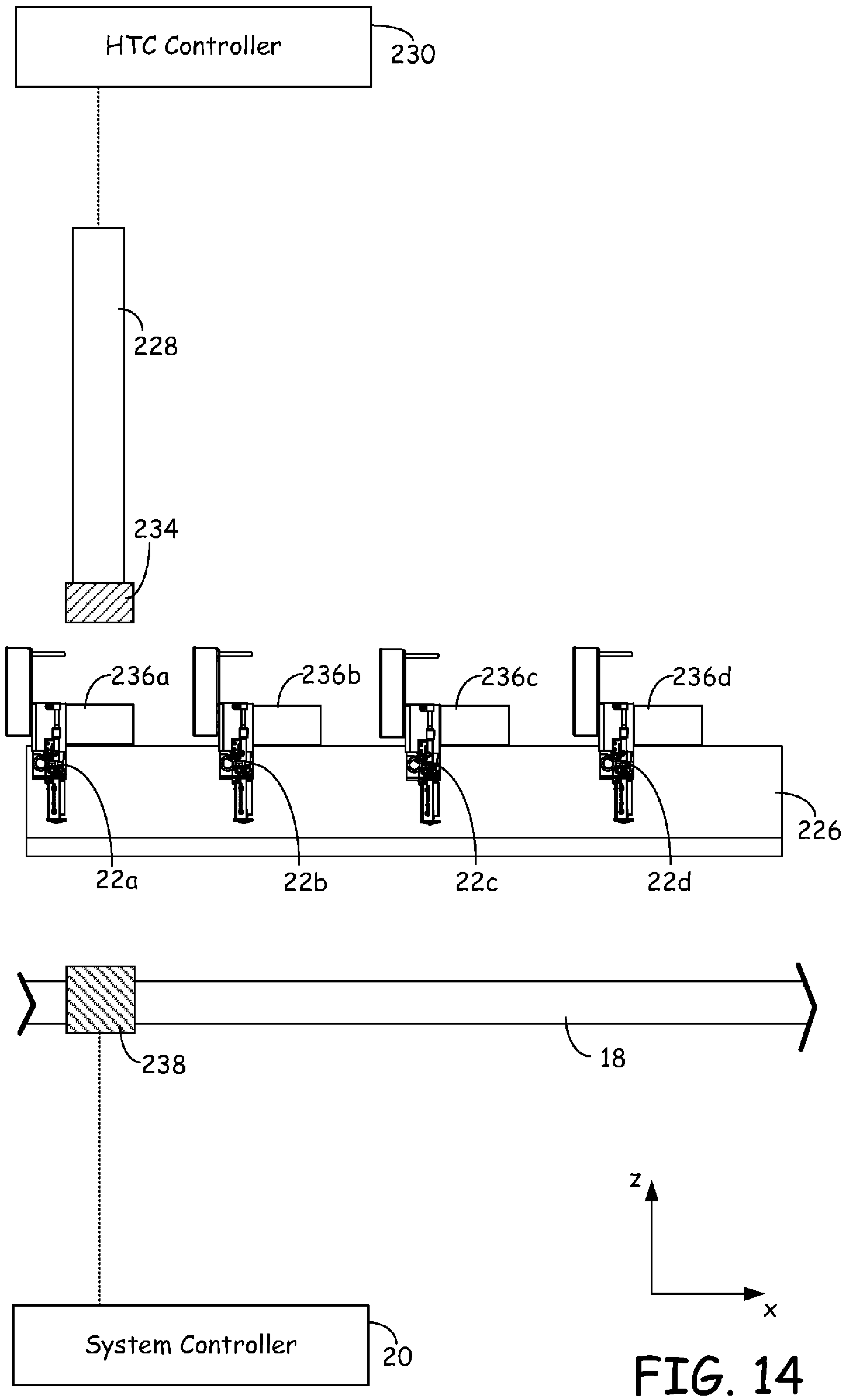
194
z
x
y

FIG. 13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22d
238
18
z
x
System Controller
20

FIG. 14

HEAD TOOL CHANGER FOR USE WITH DEPOSITION-BASED DIGITAL MANUFACTURING SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application claims priority to U.S. Provisional Patent Application No. 61/318,430, filed on Mar. 29, 2010, and entitled "HEAD TOOL CHANGER FOR USE WITH DEPOSITION-BASED DIGITAL MANUFACTURING SYSTEMS", the disclosure of which is incorporated by reference in its entirety.

BACKGROUND

The present disclosure relates to deposition-based digital manufacturing systems for building three-dimensional (3D) models with layer-based additive techniques. In particular, the present invention relates to devices for loading multiple deposition heads to deposition-based digital manufacturing systems, such as extrusion-based digital manufacturing systems.

An extrusion-based digital manufacturing system (e.g., fused deposition modeling systems developed by Stratasys, Inc., Eden Prairie, Minn.) is used to build a 3D model from a digital representation of the 3D model in a layer-by-layer manner by extruding a flowable consumable modeling material. The modeling material is extruded through an extrusion tip carried by an extrusion head, and is deposited as a sequence of roads on a substrate in an x-y plane. The extruded modeling material fuses to previously deposited modeling material, and solidifies upon a drop in temperature. The position of the extrusion head relative to the substrate is then incremented along a z-axis (perpendicular to the x-y plane), and the process is then repeated to form a 3D model resembling the digital representation.

Movement of the extrusion head with respect to the substrate is performed under computer control, in accordance with build data that represents the 3D model. The build data is obtained by initially slicing the digital representation of the 3D model into multiple horizontally sliced layers. Then, for each sliced layer, the host computer generates a build path for depositing roads of modeling material to form the 3D model.

In fabricating 3D models by depositing layers of a modeling material, supporting layers or structures are typically built underneath overhanging portions or in cavities of objects under construction, which are not supported by the modeling material itself. A support structure may be built utilizing the same deposition techniques by which the modeling material is deposited. The host computer generates additional geometry acting as a support structure for the overhanging or free-space segments of the 3D model being formed. Consumable support material is then deposited from a second nozzle pursuant to the generated geometry during the build process. The support material adheres to the modeling material during fabrication, and is removable from the completed 3D model when the build process is complete.

SUMMARY

An aspect of the present disclosure is directed to a head tool changer for use with a deposition-based digital manufacturing system. The head tool changer includes a tooling unit configured to retain a deposition head of the system, and an actuator assembly operably mounted to the system, where at least a portion of the actuator assembly is configured to move along an axis. The head tool changer also includes a grip unit secured to the actuator assembly and configured to engage with tooling unit and to relay electrical power to the tooling unit, and a master unit operably mounted to a gantry of the system, where the master unit is configured to engage with the tooling unit and to relay electrical power to the tooling unit.

Another aspect of the present disclosure is directed to a head tool changer for use with a deposition-based digital manufacturing system, where the head tool changer includes a plurality of tooling units, each being configured to retain a deposition head of the system, and a plurality of actuator assemblies operably mounted to the system, where at least a portion of each of the plurality of actuator assemblies is configured to move along an axis. The head tool changer also includes a plurality of grip units secured to the plurality of actuator assemblies, where each grip unit is configured to engage with one of the tooling units, and a master unit operably mounted to a gantry of the system, where the tooling units are configured to interchangeably engage with the master unit.

Another aspect of the present disclosure is directed to a method for changing deposition heads in a deposition-based digital manufacturing system. The method includes providing a grip unit engaged with a tooling unit, where the tooling unit is secured to one of the deposition heads, relaying electrical power through the grip unit and the tooling unit to the secured deposition head, and engaging the tooling unit with a master unit that is operably mounted to a gantry of the system. The method also includes cutting the relay of the electrical power through the grip unit and the tooling unit, relaying electrical power through the master unit and the tooling unit to the secured deposition head while the tooling unit is engaged with the master unit, and disengaging the grip unit from the tooling unit.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a front view of a deposition-based digital manufacturing system in use with a head tool changer of the present disclosure.

FIGS. **2**A-**2**P are schematic illustrations of a process for interchangeably loading deposition heads to a gantry of the digital manufacturing system with the use of the head tool changer.

FIG. **3** is a schematic illustration of the engagements between a grip unit, a tooling unit, and a master unit of the head tool changer.

FIG. **4** is a front perspective view of a tool rest assembly and actuator assemblies of the head tool changer.

FIG. **5** is a rear perspective view of the tool rest assembly and the actuator assemblies of the head tool changer.

FIG. **6** is a first side perspective view of one of the actuator assemblies and grip units retaining a tooling unit and a deposition head.

FIG. **7** is a second side perspective view of the actuator assembly and the grip unit retaining the tooling unit and the deposition head, which is taken from an opposing side from the view shown in FIG. **6**.

FIG. **8** is a top perspective view of the tooling unit and the deposition head engaged with the master unit.

FIG. **9**A is a top perspective view of the grip unit.

FIG. **9**B is a bottom perspective view of the grip unit.

FIG. **10**A is a top perspective view of the tooling unit.

FIG. **10**B is a bottom perspective view of the tooling unit.

FIG. **11**A is a top perspective view of the master unit.

FIG. **11**B is a bottom perspective view of the master unit.

FIG. **12**A is a top perspective view of the grip unit, the tooling unit, and the master unit.

FIG. **12**B is a bottom perspective view of the grip unit, the tooling unit, and the master unit.

FIG. **13** is a rear perspective view of a portion of the tool rest assembly in use with a deposition head retained by the actuator assembly.

FIG. **14** is a schematic illustration of an alternative head tool changer of the present disclosure.

DETAILED DESCRIPTION

The present disclosure is directed to a head tool changer that may be mounted to a direct digital manufacturing system, such as a deposition-based digital manufacturing system. The head tool changer is configured to interchangeably load multiple deposition heads to a gantry of the digital manufacturing system, where the multiple deposition heads may be used to build 3D models and support structures using a layer-based additive technique. As discussed below, this allows 3D models and support structures to be built with multiple materials, may reduce transition times when switching materials, and may allow operators to service and repair idle deposition heads while 3D model and support structures are being built.

FIG. **1** is a front view of system **10** in use with head tool changer **12**, where system **10** is a deposition-based digital manufacturing system and head tool changer **12** is an example of a suitable head tool changer of the present disclosure. Suitable deposition-based digital manufacturing systems for system **10** include extrusion-based systems and/or jetting systems, each of which may build 3D models and corresponding support structures using a layered-based additive technique. Suitable extrusion-based systems for system **10** include fused deposition modeling systems developed by Stratasys, Inc., Eden Prairie, Minn., such as those disclosed in Comb et al., U.S. Pat. No. 5,939,008; Swanson et al., U.S. Pat. Nos. 6,722,872 and 6,776,602; and Comb et al., U.S. patent application Ser. Nos. 12/255,289 and 12/255,330; and those commercially available under the trade designation "FORTUS" from Stratasys, Inc., Eden Prairie, Minn.

System **10** includes build chamber **14**, platform assembly **16**, and gantry **18**, and bays **19***a*-**19***d*, where build chamber **14** is an enclosed environment that contains platform assembly **16** and a portion of gantry **18**. During a build operation, build chamber **14** is desirably heated to reduce the rate at which the modeling and support materials solidify after being extruded and deposited.

Platform assembly **16** is a receiving platform on which a 3D model and corresponding support structure (not shown) are built, and desirably moves along a vertical z-axis based on signals provided from system controller **20**. Examples of suitable platforms for platform assembly **16** include those disclosed in Comb et al., U.S. patent application Ser. No. 12/255,330. System controller **20** is one or more computer-operated controllers for operating system **10**, and may be located internally or externally to system **10**.

Gantry **18** is a guide rail system that is desirably configured to move a deposition head of multiple interchangeable deposition heads **22***a*-**22***d* in a horizontal x-y plane within build chamber **14** based on signals provided from system controller **20**. The horizontal x-y plane is a plane defined by an x-axis and a y-axis, where the x-axis, the y-axis, and the z-axis are orthogonal to each other. In an alternative embodiment, platform assembly **16** may be configured to move along two axes within build chamber **14** (e.g., x-z plane or the y-z plane), and the loaded deposition head may be configured to move along a single horizontal axis (e.g., the x-axis or the y-axis). Other similar arrangements may also be used such that one or both of platform assembly **16** and the loaded deposition head are moveable relative to each other.

In the shown embodiment, gantry **18** is configured to retain a single deposition head. As such, head tool changer **12** may only load one of deposition heads **22***a*-**22***d* to gantry **18** at any given time. Of course, when system **10** is not operating, all four deposition heads **22***a*-**22***d* can be removed from gantry **18**. In alternative embodiments, gantry **18** may be configured to retain multiple deposition heads, such as disclosed in Swanson et al., U.S. patent application Ser. No. 12/180,140.

Suitable deposition heads for deposition heads **22***a*-**22***d* may include a variety of different deposition-based devices, such as extrusion heads, jetting heads, and combinations thereof. Examples of suitable extrusion heads for each of deposition heads **22***a*-**22***d* include those disclosed in LaBossiere, et al., U.S. Patent Application Publication Nos. 2007/0003656 and 2007/00228590; and Leavitt, U.S. Patent Application Publication No. 2009/0035405. Alternatively, deposition heads **22***a*-**22***d* may each include one or more two-stage pump assemblies, such as those disclosed in Batchelder et al., U.S. Pat. No. 5,764,521; and Skubic et al., U.S. Patent Application Publication No. 2008/0213419. As discussed below, however, because head tool changer **12** allows deposition heads **22***a*-**22***d* to be interchangeably loaded to gantry **18**, deposition heads **22***a*-**22***d* each desirably only includes a single deposition line (e.g., a single extrusion line) rather than a pair of deposition lines that are toggled back and forth between active and non-active states.

Deposition heads **22***a*-**22***d* desirably receive consumable materials (e.g., modeling and support materials) from one or more supply sources (not shown) loaded to bays **19**. In some embodiments, the consumable materials may be provided to system **10** as filaments. In these embodiments, suitable supply sources include spools and/or spooled containers, such as those disclosed in Swanson et al., U.S. Pat. No. 6,923,634; Comb et al., U.S. Pat. No. 7,122,246; and Taatjes et al, U.S. patent application Ser. Nos. 12/255,808 and 12/255,811. Deposition heads **22***a*-**22***d* may each also receive consumable materials from two or more spools or spooled containers loaded into bays **19** to provide for a continuous operation, as disclosed in Swanson et al., U.S. Pat. No. 6,923,634.

In the shown embodiment, head tool changer **12** is secured to a top section of system **10**, and includes housing **24**, tool rest assembly **26**, and actuator assemblies **28***a*-**28***d*. Housing **24** is an exterior housing for protecting the components of head tool changer **12**. In one embodiment, housing **24** may encase tool rest assembly **26** and actuator assemblies **28***a*-**28***d*, and may include a service door (not shown) to allow an operator of system **10** to access components retained within housing **24** (e.g., deposition heads **22***a*-**22***d*). Tool rest assembly **26** is a component that allows one or more of deposition heads **22***a*-**22***d* to be initialized (e.g., warmed up and purged) prior to use. Actuator assemblies **28***a*-**28***d* are extendable components that are configured to load deposition heads **22***a*-**22***d* to gantry **18** in an interchangeable manner based on signals provided from head tool changer (HTC) controller **30**.

HTC controller **30** is also one or more computer-operated controllers for operating head tool changer **12**, and may be located internally or externally to system **10** and/or head tool changer **12**. In one embodiment, the functions of system controller **20** and HTC controller **30** may be combined into a common computer-operated controller that may be located internally or externally to system **10** and/or head tool changer **12**. Tool rest assembly **26** and actuator assemblies **28***a*-**28***d* are discussed in more detail below.

The following discussion of head tool changer **12** illustrates the use of four interchangeable deposition heads (i.e., deposition heads **22**a-**22**d). However, head tool changer **12** may be configured to load additional or fewer numbers of deposition heads to gantry **18**. Examples of suitable numbers of deposition heads for use with head tool changer **12** range from two to ten, with particularly suitable numbers ranging from three to six.

FIGS. **2**A-**2**P and **3** are schematic illustrations of a process for interchangeably loading deposition heads **22**a-**22**d to gantry **18** of system **10** with the use the head tool changer **12**. FIGS. **4-13** subsequently illustrate suitable features of the components described in FIGS. **2**A-**2**P and **3**, pursuant to one embodiment of the present disclosure. As shown in FIG. **2**A, head tool assembly **12** also includes grip units **34**a-**34**d, tooling units **36**a-**36**d, and master unit **38**. Grip units **34**a-**34**d are respectively secured to actuator assemblies **28**a-**28**d and are configured to engage with and lock to tooling units **36**a-**36**d. Tooling units **36**a-**36**d are respectively secured to deposition heads **22**a-**22**d and are configured to engage with and lock to grip units **34**a-**34**d and master unit **38**. Master unit **38** is secured to gantry **18** (e.g., in a carriage of gantry **18**) and is configured to interchangeably engage tooling units **36**a-**36**d. Accordingly, gantry **18** is configured to move master unit **38** around in the horizontal x-y plane.

As discussed below, grip units **34**a-**34**d are configured to relay electrical power and control signals from HTC controller **30** to tooling units **36**a-**36**d when tooling units **36**a-**36**d are respectively engaged with grip units **34**a-**34**d. Similarly, master unit **38** is configured to relay electrical power and control signals from system controller **20** to one of tooling units **36**a-**36**d when the given tooling unit is engaged with master unit **38**. Tooling units **36**a-**36**d are also configured to relay the received electrical power and control signals respectively to deposition heads **22**a-**22**d. As such, when tooling units **36**a-**36**d are engaged with grip units **34**a-**34**d, deposition heads **22**a-**22**d receive electrical power and control signals from HTC controller **30**. Alternatively, when one of tooling units **36**a-**36**d is engaged with master unit **38**, the corresponding deposition head receives electrical power and control signals from system controller **20**.

In the example shown in FIG. **2**A, grip units **34**a-**34**d are respectively engaged with and locked to tooling units **36**a-**36**d, thereby allowing deposition heads **22**a-**22**d to be operably retained by actuator assemblies **28**a-**28**d. As such, deposition heads **22**a-**22**d receive electrical power and control signals from HTC controller **30** via actuator assemblies **28**a-**28**d, grip units **34**a-**34**d, and tooling units **36**a-**36**d.

Actuator assemblies **28**a-**28**d are each configured to retract and extend along the vertical z-axis between a raised position and one or more lowered positions. In particular, as shown in FIG. **2**A, actuator assemblies **28**a-**28**d may extend to a resting position such that tooling plates **36**a-**36**d rest on tool rest assembly **26**. As discussed above, tool rest assembly **26** is a component on which idle deposition heads **22**a-**22**d may rest when not loaded to gantry **18**, and may be used for initializing (e.g., warming up and purging) one or more of deposition heads **22**a-**22**d for use in system **10**.

Prior to building a 3D model or support structure, HTC controller **30** may initialize (e.g., warm up and purge) one or more of deposition heads **22**a-**22**d for use in system **10**. For example, HTC controller **30** may direct head tool changer **12** may to initialize deposition head **22**a at tool rest assembly **26**. When deposition head **22**a is ready for use, system controller **20** may align gantry **18** such that master unit **38** is positioned below actuator assembly **28**a in the horizontal x-y plane to receive deposition head **22**a, as shown in FIG. **2**A.

As shown in FIG. **2**B, HTC controller **30** may then retract actuator assemblies **28**a-**28**d upward to their raised positions, as indicated by arrows **40**. This desirably positions depositions heads **22**a-**22**d vertically higher than tool rest assembly **26**. As shown in FIG. **2**C, HTC controller **30** may then direct tool rest assembly **26** to slide along the x-axis in the direction of arrow **42** to avoid obstructing actuator assemblies **28**a-**28**d.

As shown in FIG. **2**D, HTC controller **30** may then extend actuator assembly **28**a downward to an engagement position such that tooling unit **36**a engages master unit **38**, as indicated by arrow **44**. At this point, tooling unit **36**a may unlock from grip unit **34**a and lock to master unit **38**. Additionally, control of deposition head **22**a may transfer from head tool changer **12** and HTC controller **30** to system **10** and system controller **20**. In particular, deposition head **22**a may receive electrical power and control signals from system controller **20** respectively via master unit **38** and tooling unit **36**a, and the electrical power and control signals relayed through actuator assembly **28**a, grip unit **34**a, and tooling unit **36**a may be cut off.

As shown in FIG. **2**E, HTC controller **30** may then retract actuator assembly **28**a to its raised position, as indicated by arrow **46**. This correspondingly disengages grip unit **34**a from tooling unit **36**a, and raises grip unit **34**a upward into head tool changer **12**. As shown in FIG. **2**F, HTC controller **30** may then direct tool rest assembly **26** to slide back along the x-axis to extend below actuator assemblies **28**a-**28**d, as indicated by arrow **48**.

As shown in FIG. **2**G, HTC controller **30** may then direct actuator assemblies **28**a-**28**d to extend to their resting positions such that tooling units **36**b-**36**d rest on tool rest assembly **26**, as indicated by arrows **50**. At this point, system controller **20** may also direct gantry **18** to move deposition head **22**a (and tooling unit **36**a and master unit **38**) around in the horizontal x-y plane within build chamber **14** (shown in FIG. **1**), and may direct one or more feed mechanisms (not shown) to feed a consumable material through deposition head **22**a. The received consumable material is then deposited onto platform assembly **16** (shown in FIG. **1**) to build at least a portion of a 3D model or support structure using a layer-based additive technique. After each layer is complete, platform assembly **16** may be lowered by an increment along the z-axis to allow successive layers to be formed on top of the previously deposited layers.

While deposition head **22**a is functioning as the active deposition head, HTC controller **30** may also direct one or more of deposition heads **22**b-**22**d to be initialized for use in system **10**. This allows the initializations of the deposition heads **22**b-**22**d to be performed at the same time as deposition head **22**a is in use in system **10**. For example, HTC controller **30** may initialize deposition head **22**c for operation after active deposition head **22**a has completed its deposition steps. The timing sequence for initializing deposition head **22**c desirably has deposition head **22**c ready for use as soon as deposition head **22**a completes its deposition steps.

In comparison, a deposition head that contains two deposition lines (e.g., extrusion lines), such as the deposition head disclosed in Leavitt, U.S. Patent Application Publication No. 2009/0035405, typically requires the non-active deposition line to be warmed up and purged between deposition steps. Otherwise, the non-active deposition line may interfere with the deposition from the active deposition line (e.g., material may potentially leak from the non-active deposition line). These the warm up and purge processes between the deposition steps, however, accumulate over the numerous layers used to build 3D models and support structures, This can account for a substantial portion of the overall build time.

Initializing deposition heads **22***b*-**22***d* in tandem with the operation of deposition head **22***a*, however, effectively removes the delays incurred with warming up and purging non-active deposition lines, thereby substantially reducing the overall build time.

In addition, an operator of system **10** may inspect, repair, or otherwise perform work on deposition heads **22***b*-**22***d* while deposition head **22***a* continues to build the 3D model or support structure. As such, in addition to initializing the non-active deposition heads (e.g., deposition heads **22***b*-**22***d*) in tandem with the operation of the active deposition head (e.g., deposition head **22***a*), the non-active deposition heads may also be maintained while inactive, thereby reducing maintenance delays that may otherwise occur during operation.

As shown in FIG. **2**H, after deposition head **22***a* completes its deposition steps, system controller **20** may direct gantry **18** to position tooling unit **36***a* and master plate **38** below actuator assembly **28***a* in the horizontal x-y plane. HTC controller **30** may also retract actuator assemblies **28***a*-**28***d* upward to their raised positions, as indicated by arrows **52**. As discussed above, this desirably positions depositions heads **22***b*-**22***d* vertically higher than tool rest assembly **26**. As shown in FIG. **2**I, HTC controller **30** may then direct tool rest assembly **26** to slide along the x-axis in the direction of arrow **54** to again avoid obstructing actuator assemblies **28***a*-**28***d*.

As shown in FIG. **2**J, HTC controller **30** may then extend actuator assembly **28***a* downward to its engagement position, thereby allowing grip unit **34***a* to engage with and lock to tooling unit **36***a*, as indicated by arrow **56**. At this point, tooling unit **36***a* may unlock from master unit **38** and lock to grip unit **34***a*. Additionally, control of deposition head **22***a* may now transfer from system **10** and system controller **20** back to head tool changer **12** and HTC controller **30**. In particular, deposition head **22***a* may receive electrical power and control signals from HTC controller **30** via actuator assembly **28***a*, grip unit **34***a*, and tooling unit **36***a*, and the electrical power and control signals relayed through master unit **38** and tooling unit **36***a* may be cut off.

As shown in FIG. **2**K, HTC controller **30** may then retract actuator assembly **28***a* to its raised position, as indicated by arrow **58**. This correspondingly disengages tooling unit **36***a* from master unit **38**, and raises grip unit **34***a*, tooling unit **36***a*, and deposition head **22***a* upward into head tool changer **12**. As shown in FIG. **2**L, system controller **20** may then direct gantry **18** to move master unit **38** to position it below the next actuator assembly to be used (e.g., actuator assembly **28***c*) in the horizontal x-y plane, as indicated by arrow **60**.

As shown in FIG. **2**M, HTC controller **30** may then extend actuator assembly **28***c* downward to an engagement position such that tooling unit **36***c* engages master unit **38**, as indicated by arrow **62**. At this point, tooling unit **36***c* may unlock from grip unit **34***c* and lock to master unit **38**. Additionally, control of deposition head **22***c* may now transfer from head tool changer **12** and HTC controller **30** to system **10** and system controller **20**. In particular, deposition head **22***c* may receive electrical power and control signals from system controller **20** respectively via master unit **38** and tooling unit **36***c*, and the electrical power and control signals relayed through actuator assembly **28***c*, grip unit **34***c*, and tooling unit **36***c* may be cut off.

As shown in FIG. **2**N, HTC controller **30** may then retract actuator assembly **28***c* to its raised position, as indicated by arrow **64**. This correspondingly disengages tooling unit **36***c* from grip unit **34***a*, and raises grip unit **34***c* upward into head tool changer **12**. As shown in FIG. **2**O, HTC controller **30** may then direct tool rest assembly **26** to slide back along the x-axis to extend below actuator assemblies **28***a*-**28***d*, as indicated by arrow **66**.

As shown in FIG. **2**P, HTC controller **30** may then direct actuator assemblies **28***a*-**28***d* to extend downward to their resting positions such that tooling units **36***a*, **36***b*, and **36***d* rest on tool rest assembly **26**, as indicated by arrows **68**. At this point, system controller **12** may also direct gantry **18** to move deposition head **22***c* (and tooling unit **36***c* and master unit **38**) around in the horizontal x-y plane within build chamber **14** (shown in FIG. **1**). This allows deposition head **22***c* to deposit a consumable material to build an additional portion of a 3D model or support structure using the layer-based additive technique.

This process may then be repeated in a variety of patterns for building the 3D model and support structure with the materials from one or more of deposition heads **22***a*-**22***d*. As discussed above, initializing the idle deposition heads with head tool changer **12** in tandem with the operation of the active deposition head may substantially reduce the overall build time. Additionally, the interchangeability of deposition heads **22***a*-**22***d* allows deposition heads **22***a*-**22***d* to each include a single deposition line (e.g., a single extrusion line). This precludes the need for a second, non-active deposition line, which may otherwise interfere with the deposition from the active deposition line (e.g., material leakage).

Furthermore, the interchangeability of deposition heads **22***a*-**22***d* allows different materials to be deposited from deposition heads **22***a*-**22***d*. This allows the 3D model and/or support structure to each be built with multiple materials having different physical, chemical, and/or aesthetic properties. For example, deposition head **22***a* may deposit an acrylonitrile-butadiene-styrene (ABS) modeling material that is black in color, deposition head **22***b* may deposit an ABS modeling material that is red in color, deposition head **22***c* may deposit an ABS-polycarbonate modeling material that is blue in color, and deposition head **22***d* may deposit a support material for building a corresponding support structure. Building 3D models from multiple materials may increase the functional and aesthetic properties of the given 3D models compared to a 3D model built from a single material.

Moreover, deposition heads **22***a*-**22***d* may exhibit different build parameters. For example, one or more of deposition heads **22***a*-**22***d* may be a jetting head while others are extrusion heads. Additionally, deposition heads **22***a*-**22***d* may operate at different extrusion temperatures for use with different consumable materials and/or may have different extrusion tip sizes. These different parameters may be desirable in many applications and they increase the design ranges of 3D models and support structures that may be built with system **10**.

FIG. **3** is a schematic illustration of the engagements between grip unit **34***a*, tooling unit **36***a*, and master unit **38**, which corresponds to the examples shown in FIGS. **2**D and **2**J, where actuator assembly **28***a* is extended downward to its engagement position. The following discussion of deposition head **22***a*, grip unit **34***a*, tooling unit **36***a*, and master unit **38** may also apply to each additional actuator assembly of head tool changer **12** (e.g., actuator assemblies **28***b*-**28***d*) in the same manner.

As shown in FIG. **3**, when engaged together, grip unit **34***a* and tooling unit **36***a* define power line **70**, which is one or more conductive lines configured to receive electrical power from head tool changer **12** (via one or more external power lines), and to relay the electrical power to deposition head **22***a*. Additionally, grip unit **34***a* and tooling unit **36***a* define signal line **72**, which is one or more data communication lines configured to receive control signals from HTC controller **30** (via one or more external signal lines), and to relay the control signals to deposition head **22***a*.

Similarly, when engaged together, master unit **38** and tooling unit **36***a* define power line **74**, which is one or more conductive lines configured to receive electrical power from system **10** (via one or more external power lines), and to relay the electrical power to deposition head **22***a*. Additionally, master unit **38** and tooling unit **36***a* define signal line **76**, which is one or more data communication lines configured to receive control signals from system controller **20** (via one or more external signal lines), and to relay the control signals to deposition head **22***a*.

Deposition head **22***a* is secured to tooling unit **36***a*, which allows deposition head **22***a* to receive electrical power from either power line **70** or power line **72**, and to receive control signals from either signal line **72** or signal line **74**, depending on whether head tool changer **12** or system **10** is selected as the controlling system. The transfer of which system controls deposition head **22***a* may be made when tooling unit **36***a* is engaged with grip unit **34***a* and with master unit **38**.

In one embodiment, the direction of the transfer of control may be determined based on the sequence of operation and the previous state of control. For example, while actuator assembly **28***a* is loading tooling unit **36***a* and deposition head **22***a* to gantry **18** (e.g., as shown in FIG. **2**D), HTC controller **30** has initial control over deposition head **22***a*. As such, when tooling unit **36***a* engages master unit **38**, control may transfer from HTC controller **30** to system controller **20**. Alternatively, while actuator assembly **28***a* is removing tooling unit **36***a* and deposition head **22***a* from gantry **18** (e.g., as shown in FIG. **2**J), system controller **20** has initial control over deposition head **22***a*. As such, when grip unit **34***a* engages tooling unit **36***a*, control may transfer from system controller **20** to HTC controller **30**. System controller **20** and HTC controller **30** may also communicate with each other to initiate the transfers of control.

Providing electrical power and control signals to deposition head **22***a* while retained in head tool changer **12** is desirable for initializing deposition head **22***a* in tandem with the operation of another deposition head in gantry **18**. As discussed above, this can substantially reduce the overall build time. Otherwise, if the idle deposition heads only received electrical power and signal controls while loaded to gantry **18**, the non-active deposition heads would need to be loaded to gantry **18** before they could be initialized. This would effectively eliminate the benefits of head tool changer **12** for reducing overall build times.

As further shown in FIG. **3**, the engagement between grip unit **34***a* and tooling unit **36***a* also defines locking mechanism **78**, which is a first mechanism for locking tooling unit **36***a* to grip unit **34***a*. Locking mechanism **78** may function in a variety of manners, such as electromechanical or pressure-based (e.g., pneumatic or hydraulic) locks. Accordingly, when engaged together, grip unit **34***a* and tooling unit **36***a* define conduit **80**, which may be one or more power lines for supplying electrical power to locking mechanism **78** (for electromechanical locks) or one or more fluid lines for providing and expelling pressurized fluids to and from locking mechanism **78** (for pneumatic or hydraulic locks).

Similarly, the engagement between tooling unit **36***a* and master unit **38** defines locking mechanism **82**, which is a second mechanism for locking tooling unit **36***a* to master unit **38**. Locking mechanism **82** may also function in a variety of manners, such as electromechanical or pressure-based (e.g., pneumatic or hydraulic) locks. Accordingly, when engaged together, master unit **38** and tooling unit **36***a* define conduit **84**, which may be one or more power lines for supplying electrical power to locking mechanism **82** (for electromechanical locks) or one or more fluid lines for providing and expelling pressurized fluids to and from locking mechanism **82** (for pneumatic or hydraulic locks).

For example, while actuator assembly **28***a* loads tooling unit **36***a* and deposition head **22***a* to gantry **18** (e.g., as shown in FIG. **2**D), tooling unit **36***a* is initially locked to grip unit **34***a* (i.e., locking mechanism **78** is activated). As such, when tooling unit **36***a* engages master unit **38**, in addition to transferring the control of deposition head **22***a* from HTC controller **30** to system controller **20**, locking mechanism **78** may deactivate and locking mechanism **82** may activate, thereby locking tooling unit **36***a* to master unit **38**. Alternatively, while actuator assembly **28***a* is removing tooling unit **36***a* and deposition head **22***a* from gantry **18** (e.g., as shown in FIG. **2**J), tooling unit **36***a* is initially locked to master unit **38** (i.e., locking mechanism **82** is activated). As such, when grip unit **34***a* engages tooling unit **36***a*, in addition to transferring the control of deposition head **22***a* from system controller **20** back to HTC controller **30**, locking mechanism **82** may deactivate and locking mechanism **78** may activate, thereby locking tooling unit **36***a* to grip unit **34***a*. This locking arrangement provides an efficient manner for interchangeably retaining tooling unit **36***a* (and deposition head **22***a*) with either grip unit **34***a* or master unit **38**.

As discussed above, FIGS. **4**-**13** illustrate suitable features of the components described in FIGS. **2**A-**2**P and **3**, pursuant to one embodiment of the present disclosure. For ease of discussion, the components of head tool changer **12** discussed in FIGS. **4**-**13** are described with the same reference labels as those used for the components discussed in FIGS. **2**A-**2**P and **3**.

FIGS. **4** and **5** are expanded front and rear perspective views of tool rest assembly **26** and actuator assemblies **28***a*-**28***d* of head tool changer **12**. As shown in FIG. **4**, tool head changer **12** also includes cross plates **86** and **88**, and retention member **90**, each of which are desirably secured to a frame structure of head tool changer **12** (not shown). Tool rest assembly **26** may be secured to the frame structure with cross plate **86**, thereby positioning tool rest assembly **26** at a bottom front location of head tool changer **12** in the shown embodiment. Similarly, actuator assemblies **28***a*-**28***d* may each be secured to the frame structure with cross plate **88**, thereby allowing actuator assemblies **28***a*-**28***d* to be suspended over gantry **18** (shown in FIG. **1**) and tool rest assembly **26**. Retention member **90** is an additional plate configured to restrict lateral movement of actuator assemblies **28***a*-**28***d* along the y-axis.

As further shown, tool rest assembly **26** includes tool rests **92***a*-**92***d*, air circulators **94***a*-**94***d*, and purge receptacle **96**, where air circulators **94***a*-**94***d* may be secured to cross plate **86**. As discussed below, tool rests **92***a*-**92***d* and purge receptacle **96** are desirably slidable relative to cross plate **86** to slide along the x-axis, as discussed above.

Actuator assemblies **28***a*-**28***d* respectively include actuator arms **98***a*-**98***d* and guide rails **100***a*-**100***d*, where the bottom ends of actuator arms **98***a*-**98***d* are respectively secured to cross plate **88** with mounting brackets **102***a*-**102***d*. The top ends of actuator arms **98***a*-**98***d* are respectively connected to the top ends of guide rails **100***a*-**100***d*, thereby allowing the retraction and extension of actuator arms **98***a*-**98***d* to respectively move guide rails **100***a*-**100***d* upward and downward between the raised position and one or more lowered positions (e.g., the resting and engagement positions).

As shown in FIG. **5**, tool rest assembly **26** also includes slide track **104** and mounting plate **106**, where mounting plate

106 is configured to move back and forth along the x-axis on slide track **104**. HTC controller **30** may move mounting plate **106** with the use of a variety of drive mechanisms, such as pneumatic drives, hydraulic drives, and electrochemical motor drives. Tool rests **92***a*-**92***d* are secured to mounting plate **106**, and purge receptacle **96** is desirably secured to tool rests **92***a*-**92***d*. This arrangement allows tool rests **92***a*-**92***d* to slide along the x-axis, as discussed above, to avoid obstructing the lowering of actuator assemblies **28***a*-**28***d* to their engagement positions. The use of tool rests **92***a*-**92***d* and purge receptacle **96** for initializing deposition heads **22***a*-**22***d* is further discussed below.

Actuator assemblies **28***a*-**28***d* also respectively include sleeve brackets **108***a*-**108***d*, which are secured to cross plate **88**. Guide rails **100***a*-**100***d* respectively extend through sleeve brackets **108***a*-**108***d*, thereby restricting the movement of guide rails **100***a*-**100***d* to upward and downward directions along the vertical z-axis.

The following discussion in FIGS. **6**-**13** is directed to deposition head **22***a*, actuator assembly **28***a*, grip unit **34***a*, and tooling unit **36***a*. However, the discussion may also apply to deposition heads **22***b*-**22***d*, actuator assemblies **28***b*-**28***d*, grip units **34***b*-**34***d*, and tooling units **36***b*-**36***d* in the same manner. FIGS. **6** and **7** are opposing side perspective views of grip unit **34***a* and tooling unit **36***a* operably connecting guide rail **100***a* and deposition head **22***a*.

As shown in FIG. **6**, grip unit **34***a* includes base component **110**, compensator **112**, leads **114***a* and **114***b*, and couplings **116**. Base component **110** is the portion of grip unit **34***a* that engages with and is lockable to tooling unit **36***a* with locking mechanism **78** (shown in FIG. **3**). In the shown embodiment, base component **110** is fabricated from multiple sub-blocks that are secured together with fasteners. In an alternative embodiment, base component **110** may be fabricated as an integral block. Compensator **112** is secured to the top surface of base component **110**, and is the portion of grip unit **34***a* that is secured to the bottom end of guide rail **102***a*. As discussed below, compensator **112** allows tooling unit **36***a* to float laterally and vertically when engaging tooling unit **36***a* with master unit **38**.

Leads **114***a* and **114***b* are electrical connections secured to base component **110**, and are configured to be connected to external cables (not shown) to receive electrical power and control signals from head tool changer **12** and HTC controller **30**, as discussed above for power line **70** and signal line **72** (shown in FIG. **3**).

Couplings **116** are gas couplings secured to base component **110**, and are configured to be connected to external fluid conduits (not shown) to receive and expel pressurized gases to operate locking mechanism **78**, as discussed above for conduit **80** (shown in FIG. **3**). Accordingly, in this embodiment, locking mechanism **78** may function as a pneumatic locking mechanism. In one embodiment, the external fluid conduits for supplying and recycling the pressurized gases may also extend along or within actuator arm **98***a* and guide rail **100***a* to connect with couplings **116**.

Tooling unit **36***a* includes base component **118**, which is secured to deposition head **22***a* and is the portion of tooling unit **36***a* that engages with and is lockable to base component **110** of grip unit **34***a* with locking mechanism **78**. In the shown embodiment, base component **118** is also fabricated from multiple sub-blocks that are secured together with fasteners. In an alternative embodiment, base component **118** may be fabricated as an integral block.

As further shown in FIG. **6**, actuator assembly **28***a* also includes electrical connections **120** adjacent to mounting bracket **102***a*, where electrical connections **120** are configured to receive electrical power and control signals from head tool changer **12** and HTC controller **30** via one or more external electrical cables (not shown). This allows HTC controller **30** to direct the operation of actuator assembly **28***a* for raising and lowering guide rail **100***a* along the vertical z-axis. In addition, one or more cables (not shown) may also extend along or within actuator arm **98***a* and guide rail **100***a*, thereby relaying the electrical power and control signals from electrical connections **120** to leads **114***a* and **114***b* of grip unit **34***a*.

In the shown embodiment, deposition head **22***a* includes control board **122**, drive mechanism **124**, thermal block **126**, and extrusion tip **128**, which may form a single extrusion line, such as a single extrusion line of the extrusion head described in Leavitt, U.S. Patent Application Publication No. 2009/0035405. Drive mechanism **124** may receive a filament of a consumable material from one or more supply sources retained in bays **19** (shown in FIG. **1**) through guide tube **130**.

As shown in FIG. **7**, deposition head **22***a* also include bracket **132**. Bracket **132** is a frame component of deposition head **22***a* and may retain control board **122**, drive mechanism **124**, and thermal block **126**. Bracket **132** is also the portion of deposition head **22***a* that may be secured to base component **118** of tooling unit **36***a*.

FIG. **8** is a front perspective view of tooling unit **36***a* and deposition head **22***a* engaged with master unit **38**. As shown, control board **122** of deposition head **22***a* includes power connection ports **134***a* and **134***b*, and signal connection ports **135***a* and **135***b*, which are configured to receive electrical power and control signals from tooling unit **36***a* via external cables (not shown). For example, power connection port **134***a* and signal connection port **135***a* are configured to receive electrical power and control signals from grip unit **34***a* and tooling unit **36***a*, as discussed above for power line **70** and signal line **72** (shown in FIG. **3**). Correspondingly, power connection port **134***b* and signal connection port **135***b* are configured to receive electrical power and control signals from master unit **38** and tooling unit **36***a*, as discussed above for power line **74** and signal line **76** (shown in FIG. **3**).

Tooling unit **36***a* also includes electrical contacts **136***a* and **136***b*, lock ring **138**, guide holes **140**, and top surface **142**, where top surface **142** is the surface of base component **118** that engages with grip unit **34***a*. Electrical contacts **136***a* and **136***b* are conductive contacts located at top surface **142**, and are configured to engage with reciprocating electrical contacts (not shown in FIG. **8**) located at a bottom surface of grip unit **34***a*. This allows the electrical power and control signals that are received through leads **114***a* and **114***b* of grip unit **34***a* (shown in FIGS. **6** and **7**) to be relayed to tooling unit **36***a*, as discussed above.

Lock ring **138** is a female portion of locking mechanism **78** (shown in FIG. **3**) disposed in base component **118** at top surface **142**. Lock ring **138** is configured to receive a reciprocating male portion of locking mechanism **78** retained by grip unit **34***a* for locking tooling unit **36***a* to grip unit **34***a*.

Guide holes **140** are a pair of holes extending within base component **118** at top surface **142**, and are configured to receive guide pins (not shown in FIG. **8**) extending from the bottom surface of grip unit **34***a*. This arrangement allows the guide pins to align with guide holes **140** when grip unit **34***a* and tooling unit **36***a* engage each other.

As further shown in FIG. **8**, master unit **38** includes base component **144**, leads **146***a* and **146***b*, and couplings **148**. Base component **144** is the portion of master unit **38** that engages with and is lockable to the bottom surface of tooling unit **36***a* with locking mechanism **82** (shown in FIG. **3**). Base component **144** is also the portion that may be secured to a carriage of gantry **18**, such as in an adjustable head mount as disclosed in Comb et al., U.S. patent application Ser. No. 12/255,289. In the shown embodiment, base component **144** is also fabricated from multiple sub-blocks that are secured together with fasteners. In an alternative embodiment, base component **144** may be fabricated as an integral block.

Leads **146***a* and **146***b* are electrical connections secured to base component **144**, and are configured to be connected to external cables (not shown) to receive electrical power and control signals from system **10** and system controller **20**, as discussed above for power line **74** and signal line **76** (shown in FIG. **3**). Couplings **148** are gas couplings secured to base component **144**, and are configured to be connected to external fluid conduits (not shown) to receive and expel pressurized gases to operate locking mechanism **82**, as discussed above for conduit **84** (shown in FIG. **3**). Accordingly, in this embodiment, locking mechanism **82** may also function as a pneumatic locking mechanism.

FIGS. **9**A and **9**B are respectively top and bottom perspective views of grip unit **34***a*. As shown in FIG. **9**A, compensator **112** includes top surface **150**, springs **152**, and electrical ports **154**, and is configured to switch between an unlocked state and a locked state based on signals received through electrical ports **154**. Top surface **150** is the portion of compensator **112** that may be secured to the bottom end of guide rail **100***a* (shown in FIGS. **4-7**). While in the unlocked state, springs **152** allow grip unit **34***a* (and tooling unit **36***a* when engaged with grip unit **34***a*) to float laterally and vertically. This correspondingly provides grip unit **34***a* a small freedom of movement when actuator assembly **28***a* is aligning with master unit **38**. As such, when deposition head **22***a* is being loaded to gantry **18**, compensator **112** is desirably set to the unlocked state while grip unit **34***a* and tooling unit **36***a* align and engage with master unit **38**. When tooling unit **36***a* engages with master unit **38**, compensator **112** may then be locked to prevent further lateral or vertical floating.

As shown in FIG. **9**B, grip unit **34***a* further includes bottom surface **156**, electrical contacts **158***a* and **158***b*, lock extension **160**, and guide pins **162**. Bottom surface **156** is the surface of grip unit **34***a* that may engage with top surface **142** of tooling unit **36***a* (shown in FIG. **8**). Electrical contacts **158** and **158***b* are conductive contacts located at bottom surface **156**, and are configured to engage with electrical contacts **136***a* and **136***b* (shown in FIG. **8**) of tooling unit **36***a*.

Lock extension **160** is a male portion of locking mechanism **78** (shown in FIG. **3**) extending from bottom surface **156**, and is configured to extend into lock ring **138** of tooling unit **36***a* for locking grip unit **34***a* to tooling unit **36***a*. In the shown embodiment, lock extension **160** includes a plurality of plugs that are capable of expanding outward and contracting inward from lock extension **160** based on the pressure within lock extension **160**. As a result, lock extension **160** may be secured to lock ring **138** by introducing pressurized gas through couplings **116**, which cause the plugs to expand outward to physically trap lock extension **160** in lock ring **138**. Guide pins **162** are a pair of pins extending downward from bottom surface **156**, and are configured to engage guide holes **140** of tooling unit **36***a*, as discussed above.

FIGS. **10**A and **10**B are respectively top and bottom perspective views of tooling unit **36***a*. As shown in FIG. **10**A, tooling unit **36***a* also includes lateral surface **164**, power connection ports **166***a* and **166***b*, and signal connection ports **168***a* and **168***b*. Lateral surface **164** is the surface of tooling unit **36***a* that may be secured to bracket **132** of deposition head **22***a* to secure deposition head **22***a* to tooling unit **36***a*. Power connection ports **166***a* and **166***b*, and signal connection ports **168***a* and **168***b* are configured to relay electrical power and control signals from tooling unit **36***a* respectively to power connection ports **134***a* and **134***b* and signal connection ports **135***a* and **135***b* of deposition head **22***a*, via external cables (not shown). As discussed above, this arrangement allows deposition head **22***a* to receive electrical power and control signals from power line **70** and signal line **72** (shown in FIG. **3**) that are relayed through grip unit **34***a* and tooling unit **36***a*, and from power line **74** and signal line **76** (shown in FIG. **3**) that are relayed through master unit **38** and tooling unit **36***a*.

As shown in FIG. **10**B, tooling unit **36***a* further includes bottom surface **170**, electrical contacts **172***a* and **172***b*, lock ring **174**, guide holes **176**, and mating guides **178**. Bottom surface **170** is the surface of tooling unit **36***a* that may engage with master unit **38**. Electrical contacts **172***a* and **172***b* are conductive contacts secured to base component **118**, and are configured to engage with reciprocating electrical contacts of master unit **38** (not shown in FIG. **10**B).

Lock ring **174** is a female portion of locking mechanism **82** (shown in FIG. **3**) disposed in bottom surface **170**, and is configured to receive a lock extension of master unit **38** (not shown in FIG. **10**B). Guide holes **176** are a pair of holes extending within bottom surface **170** and are configured to receive guide pins of master unit **38** (not shown in FIG. **10**B). Mating guides **178** are a plurality of guides configured to receive domes (not shown in FIG. **10**B) of master unit **38**. As discussed below, the engagement between the domes and mating guides **178** provide a precision mating mechanism for tooling unit **36***a* and master unit **38**.

FIGS. **11**A and **11**B are respectively top and bottom perspective views of master unit **38**. As shown, master unit **38** also includes top surface **180**, electrical contacts **182***a* and **182***b*, lock extension **184**, guide pins **186**, and domes **188**. Top surface **180** is the surface of master unit **38** that may engage with bottom surface **170** of tooling unit **36***a*. Electrical contacts **182***a* and **182***b* are conductive contacts located at top surface **180**, are configured to engage with electrical contacts **172***a* and **172***b* of tooling unit **36***a*. This allows the electrical power and control signals that are received through leads **146***a* and **146***b* to be relayed to tooling unit **36***a*, as discussed above.

Lock extension **184** is a male portion of locking mechanism **82** (shown in FIG. **3**) extending from top surface **180**, and may function in the same manner as lock extension **160** (shown in FIG. **9**B). Accordingly, lock extension **184** is configured to extend into lock ring **174** of tooling unit **36***a*, thereby allowing master unit **38** to lock to tooling unit **36***a* based on the pressurized gases received via couplings **148**. Guide pins **186** are a pair of pins extending upward from top surface **180**, and are configured to engage guide holes **176** located bottom surface **170** of tooling unit **36***a*. This arrangement allows guide pins **186** to align with guide holes **176** when tooling unit **36***a* and master unit **38** engage each other.

Domes **188** are a plurality of topographical features (e.g., half spheres) extending above the plane of top surface **180** and are configured to engage with mating guides **178** to provide a precision mating mechanism. In the shown embodiment in which master unit **38** includes three domes **188** and tooling unit **36***a* includes three mating guides **178**, this precision mating provides six degrees of restraint. This restraint defines a rigid body that resists lateral movement of tooling unit **36***a* relative to master unit **38** in the horizontal x-y plane when tooling unit **36***a* is locked to master unit **38**. This is desirable to allow gantry **18** to prevent tooling unit **36***a* and deposition head **22***a* from moving laterally relative to master unit **38** during operation in system **10**.

FIGS. 12A and 12B are respectively top and bottom exploded perspective views of grip unit 34a, tooling unit 36a, and master unit 38, which illustrate their respective engagements with each other. For example, when grip unit 34a is lowered onto tooling unit 36a to retract tooling unit 36a from master unit 38 (e.g., as shown in FIG. 2J), guide pins 162 may enter guide holes 140 to align grip unit 34a with tooling unit 36a, and lock extension 160 may enter lock ring 138. The lateral freedom attained with compensator 112 in the unlocked state reduces the risk of damage to grip unit 34a and tooling unit 36a during the alignment.

When grip unit 36a engages tooling unit 36a, electrical contacts 158a and 158b of grip unit 34a engage with electrical contacts 136a and 136b of tooling unit 36a, thereby allowing electrical power and control signals to be relayed from leads 114a and 114b of grip unit 34a to electrical contacts 166a and 168a of tooling unit 36a. Head tool changer 12 may then introduce pressurized gas into couplings 116 to engage lock extension 160 within lock ring 138 to lock tooling unit 36a to grip unit 34a. Additionally, compensator 112 may be locked to restrict lateral movement.

System 10 may also release the pressurized gas from couplings 148 to unlock lock extension 184 from lock ring 174, thereby unlocking tooling unit 36a from master unit 38. Additionally, transfer of electrical power and signal control of deposition head 22a to HTC controller 30 may also occur after electrical contacts 158a and 158b engage with electrical contacts 136a and 136b. Actuator assembly 28a may then raise grip unit 34a to disengage tooling unit 36a from master unit 38, as discussed above.

Alternatively, when grip unit 34a and tooling unit 36a are lowered onto master unit 38 (e.g., as shown in FIG. 2D), guide pins 186 may enter guide holes 176 to align tooling unit 36a with master unit 38, and lock extension 184 may enter lock ring 174. The lateral freedom attained with compensator 112 in the unlocked state also reduces the risk of damage to tooling unit 36a and master unit 38 during this alignment.

When tooling unit 36a engages master unit 38, electrical contacts 172a and 172b of tool unit 36a engage with electrical contacts 182a and 182b of master unit 38, thereby allowing electrical power and control signals to be relayed from leads 144a and 144b of master unit 38 to electrical contacts 166b and 168b of tooling unit 36a. Head tool changer 12 may then introduce pressurized gas into couplings 148 to engage lock extension 184 within lock ring 174 to lock tooling unit 36a to master unit 38. Additionally, compensator 112 may be locked to restrict lateral movement.

Head tool changer 12 may also release the pressurized gas from couplings 116 to unlock lock extension 160 from lock ring 138, thereby unlocking grip unit 34a from tooling unit 36a. Additionally, transfer of electrical power and signal control of deposition head 22a to system controller 20 may also occur after electrical contacts 172a and 172b engage with electrical contacts 182a and 182b. Actuator assembly 28a may then raise grip unit 34a disengage grip unit from tooling unit 36a, as discussed above.

FIG. 13 is a rear perspective view of a portion of tool rest assembly 26 in use with deposition head 22a retained by actuator assembly 28a, where deposition head 22a may be retained at tool rest 92a when not loaded to gantry 18, as discussed above in FIG. 2P. As shown in FIG. 13, tool rest 92a includes tool mount 190, purge trap 192, and purge line 194. Tool mount 190 extends above purge trap 192 and includes top surface 196 and guide pins 198. Top surface 196 is the surface of tool rest 92a that may engage with bottom surface 170 of tooling unit 36a. Furthermore, guide pins 198 are configured to engage with guide holes 176 of tooling unit 36a, thereby aligning deposition head 22a into purge trap 192.

When tooling unit 36a rests on top surface 196 of tool mount 190, a portion of thermal block 126 and extrusion tip 128 extend into purge trap 192. Purge trap 192 is a secondary trap for collecting any excess purge material that does not travel into purge line 194. Purge line 194 interconnects purge trap 192 and purge receptacle 96 (shown in FIGS. 4 and 5) for directing purge material to purge receptacle 96. In one embodiment, purge receptacle 96 may be connected to a vacuum line (not shown) to actively draw purge materials through purge line 194 into purge receptacle 96. In an alternative embodiment, purge receptacle 96 may be omitted and purge line 194 may be directly connected to a vacuum line.

During an initialization process to warm up and purge deposition head 22a, deposition head 22a desirably rests on tool rest 92a. HTC controller 30 (shown in FIG. 1) may then power up deposition head 22a and heat up thermal block 126 to an operating temperature. HTC controller 30 may the direct drive mechanism 124 to feed successive portions of a consumable material to thermal block 126. The consumable material may then melt in thermal block 126 and deposit from extrusion tip 128 for a preset purge period.

During the purge operation, air circulator 94a also desirably directs cooling air to drive mechanism 124 and/or the entrance of thermal block 126 to prevent the consumable material from melting at the entrance of thermal block 126. Gantry 18 (shown in FIG. 1) may also include an additional cooling manifold (not shown) for use with a deposition head in system 10. However, air circulators 94a-94d allow the non-active deposition heads 22a-22d to also receive cooling air to prevent premature melting of the consumable materials during purge operations.

FIG. 14 is a schematic illustration of head tool changer 212, which is an example of an alternative head tool changer of the present disclosure for use with system 10. Head tool changer 212 functions in a similar manner as head tool changer 12, and the corresponding reference labels are increased by "200". As shown, head tool changer 212 includes a single actuator assembly 228 and a single grip unit 234 rather than multiple actuator assemblies and grip units. Accordingly, HTC controller 30 is further configured to slide tool rest assembly 226 along the x-axis to position tooling units 236a-236d below grip unit 234 in the horizontal x-y plane, thereby allowing actuator assembly 226 and grip unit 234 to selectively retain tooling units 236a-236d and deposition heads 22a-22d in an interchangeable manner for loading and uploading to and from master unit 238.

In one embodiment, the tool rests of actuator assembly 226 may each provide electrical power and control signals to deposition heads 22a-22d while tooling units 236a-236d rest on the tool rests of actuator assembly 226. In this embodiment, HTC control 230 may also be connected to the tool rests of actuator assembly 226 to relay electrical power and control signals to tooling units 236a-236d and deposition heads 22a-22d. This arrangement allows one or more deposition heads 22a-22d to be warmed up while disengaged from actuator assembly 228. Examples of suitable electrical connections include those discussed above for master units 38, 138, and 238, thereby allowing deposition heads 22a-22d to be powered and controlled from connections located below tooling units 236a-236d.

Accordingly, during operation, tool rest assembly 226 may slide along the x-axis to position one of tooling units 236a-236d below grip unit 234, and actuator assembly 228 may then extend downward to engage and lock grip unit 234 to the given tooling unit. Actuator assembly 228 may then retract to its raised position, tool rest assembly **226** may then slide out of the way (e.g., as shown above in FIG. **2**C), and actuator assembly **228** may then extend downward to its engagement position to engage the given tooling unit with master unit **238**, as discussed above. This process discussed above in FIGS. **2**A-**2**P may then be applied to selectively load tooling units **236***a*-**236***d* and deposition heads **22***a*-**22***d* to master unit **238** and gantry **18** in an interchangeable manner.

In an alternative embodiment, actuator assembly **228** may also be movable along the x-axis to selectively position grip unit **234** over tooling units **236***a*-**236***d*. Accordingly, the tool head changers of the present disclosure (e.g., head tool changers **12** and **212**) may include at least one actuator assembly and at least one grip unit for loading deposition heads to gantry **18** of system **10**.

Furthermore, in one embodiment, deposition heads may be supplied to head tool changers **12** and **212** in magazines, turrets, and other similar carrier units. For example, tool rest assemblies **26** and **226** may each be loadable and unloadable to and from head tool changers **12** and **212** This arrangement allows different deposition heads to be supplied to head tool changer **212**. When each supply of deposition heads is provided to head tool changer **212** or **212**, the given system may then perform a calibration routine to align grip units **34***a*-**34***d* and **234** with the corresponding tooling units **36***a*-**36***d* and **236***a*-**236***d*. The supplied deposition heads may then undergo initializations and may be loaded to gantry **18** in an interchangeable manner, as discussed above. This increases the versatility of the head tool changers in providing multiple deposition heads to system **10**.

Although the present disclosure has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the disclosure.

The invention claimed is:

1. A head tool changer for use with a deposition-based digital manufacturing system for building layer-based three-dimensional models, the head tool changer comprising:

a tooling unit configured to retain a deposition head of the deposition-based digital manufacturing system;

a master unit operably mounted to a gantry of the deposition-based digital manufacturing system, the master unit being configured to detachably engage with the tooling unit and to relay electrical power to the tooling unit;

an actuator assembly operably mounted to the deposition-based digital manufacturing system, wherein at least a portion of the actuator assembly is configured to move along an axis toward the master unit; and

a grip unit secured to the actuator assembly and configured to detachably engage with the tooling unit and to relay electrical power to the tooling unit;

wherein the relay of electrical power from the grip unit to the tooling unit is configured to be cut upon the tooling unit being disengaged from the grip unit and being engaged with the master unit.

2. The head tool changer of claim **1**, wherein the tooling unit is further configured to relay the electrical power received from the grip unit to the deposition head when the deposition head is engaged with the grip unit, and wherein the tooling unit is further configured to relay the electrical power received from the master unit to the deposition head when the deposition head is engaged with the master unit.

3. The head tool changer of claim **1**, wherein the grip unit and the master unit are each further configured to relay control signals to the tooling unit.

4. The head tool changer of claim **1**, wherein the tooling unit comprises:

a first electrical contact configured to receive at least a portion of the electrical power relayed from the grip unit; and

a second electrical contact configured to receive at least a portion of the electrical power relayed from the master unit.

5. The head tool changer of claim **4**, wherein the grip unit comprises:

an electrical lead configured to receive the electrical power relayed to the tooling unit from the head tool changer; and

a third electrical contact conductively connected to the electrical lead and configured to engage with the first electrical contact of the tooling unit.

6. The head tool changer of claim **4**, wherein the master unit comprises:

an electrical lead configured to receive the electrical power relayed to the tooling unit from the deposition-based digital manufacturing system; and

a third electrical contact conductively connected to the electrical lead and configured to engage with the second electrical contact of the tooling unit.

7. The head tool changer of claim **1** further comprising a tool rest assembly operably mounted to the deposition-based digital manufacturing system, the tool rest assembly configured to engage with the tooling unit.

8. The head tool changer of claim **7**, wherein the tool rest assembly comprises a purge trap that is configured to be operably connected to a vacuum line.

9. The head tool changer of claim **7**, wherein the tool rest assembly is further configured to relay electrical power and control signals to the tooling unit when engaged with the tooling unit.

10. A head tool changer for use with a deposition-based digital manufacturing system for building layer-based three-dimensional models, the head tool changer comprising:

a plurality of tooling units, each tooling unit being configured to retain a respective deposition head of the deposition-based digital manufacturing system;

a master unit operably mounted to a gantry of the deposition-based digital manufacturing system, wherein the tooling units are configured to interchangeably engage with the master unit such that only one of the plurality of tool units engages the master unit at any given time;

a plurality of actuator assemblies operably mounted to the deposition-based digital manufacturing system, wherein at least a portion of each of the plurality of actuator assemblies is configured to move along an axis toward the master unit; and

a plurality of grip units, wherein each grip unit is secured to one of the plurality of actuator assemblies, each grip unit being configured to detachably engage with one of the plurality of tooling units;

wherein the grip units are each configured to relay electrical power to the respective tooling unit attached thereto, and wherein the relay of electrical power from one of the grip units to the respective tooling unit attached thereto is configured to be cut upon the respective tooling unit being disengaged from the one grip unit and being engaged with the master unit.

11. The head tool changer of claim **10**, wherein the electrical power relayed from each grip unit to the respective tooling unit attached thereto is configured to power the deposition head secured to the respective tooling unit.

12. The head tool changer of claim **11**, wherein each grip unit is further configured to relay control signals to the respective tooling unit attached thereto, the relayed control signals being configured to operate the deposition head secured to the respective tooling unit.

13. The head tool changer of claim **10**, wherein the master unit is configured to relay electrical power to one of the plurality of tooling units at a given time, the relayed electrical power being configured to power the deposition head secured to the one tooling unit.

14. The head tool changer of claim **10**, wherein each tooling unit comprises:

a first lock component configured to lock with a portion of the respective grip unit attached thereto; and

a second lock component configured to lock with a portion of the master unit.

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